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MEDICAL AND SOCIAL PROBLEMS OF AGING

by
R. E. TUNBRIDGE

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INTRODUCTION

The problems of aging are not new phenomena. Throughout history man has been aware that both he and the animals he hunted or kept in domesticity had a limited existence, and that with the passage of the years a decline in activity, strength and fertility would occur. Strictly speaking, aging denotes merely the passage of years, but it has come to have a sinister meaning and to imply the deterioration that so frequently accompanies it and is perhaps best referred to as senescence.

Historical records relate the existence of men still distinguished in their 60's, 70's and even 80's. In the Bible there is the record of Methuselah which, even allowing for literary licence and a method other than ours of estimating time, would suggest that he attained what we would call a ripe old age!

The comparative scarcity of true veterans until recent times has meant that nearly all the descriptions of the elderly have come from the pens of young men. Senescence, or the evidence thereof, has entered so early and so untimely into human experience that almost all studies of the phenomenon have been confused with the associated metaphysical problems.

Greek thought has influenced western philosophy so profoundly that it is not surprising that the Grecian attitude to age has in part been adopted by western civilization. The Greeks certainly paid lip service to the aged, and whilst octogenarians figure amongst their great philosophers, it was youth that for them was the age of perfection. Sophocles, referring to old age, says: 'The understanding is quenched, what is done is unprofitable and thereby griefs are vain.' Aging was something to be dreaded because of the physical disabilities and deterioration that accompanied it. The young, possibly because the true elders were few in number, tended to refer and to think of the elderly collectively—in terms of a group rather than of individuals—assuming that disability was a feature of all old age, without allowing

for the individual variation they accepted as axiomatic in themselves.

Not all Greeks held disparaging views about aging. In Sparta the constitution of Lycurgus provided a three-tier structure of government—the kings, the five ephors, and the Gerousia. The latter consisted of 28 men over the age of 60, who were elected by popular ballot, having previously indicated their willingness to stand for election. The power of the Gerousia was however restricted. They could not elect a president from their own number, one of the kings acting in this capacity, and they could only be convened by the ephors. They were in fact an advisory body, but they held a privileged position in the society of Sparta, which may account for the Greek proverb: 'Only in Sparta is it good to grow old.'

The abhorrence of age was a feature of other communities, and in many nomad and hunting tribes the elderly men, once they became unable to defend themselves, were killed or were isolated from the tribe. Among the Gran Chaco Indians it was considered the son's duty to kill his father as soon as he was unable to keep up with the tribe.

In contrast to most other communities, the Chinese have revered old age from the earliest days of their history. 'And what is your honourable age?' is one of the polite questions asked on paying a call. This veneration of the elderly was advocated by Confucius as an ethical duty, but this ethical aspect assumed a more mystical significance through the linkage of Confucianism with Taoism. The Chinese, however, despite their reverence for the aged, were not oblivious of the physical and mental incapacities of the aged, and some of their poems reveal perhaps the greatest insight into the significance of aging to the aged.

WHAT IS SENESCENCE?

Increasing years should benefit the animal's chance of survival, for with greater knowledge and experience it should be able to avoid some of the hazards of life and, as a result of wider contacts, develop a greater degree of immunity to infections. This could be true for man, but because of the associated disabilities that accompany chronological aging, the word has become synonymous both in literature and science with senescence. Man has always been interested in the cause of senescence. Is it a state of physical exhaustion, a matter of wear and tear, a genetically determined phenomenon, the result of environmental stress, the accumulation of toxic substances, the breakdown of a metabolic cycle, a lack of enzymatic action, the failure of a specific organ or organs, or a natural event? These and many other theories have been propounded and still have their exponents. The surprising feature is the lack of variety in the theories of aging. The same themes recur throughout history, suggesting that the metaphysical concepts of society with regard

to aging have also influenced the scientists, with a consequent lack of, and search for, objective data.

The use of special functions, such as fertility, as a measure of senescence demonstrates admirably the difficulties of the subject. Eckstein[1] cites the comparison of one year in the life of a mouse, a dog and a human being: 'At its end the mouse has passed through puberty, delivered probably most of the young it is likely to, and has at most another twelve months to live. The bitch is then sexually mature, but will probably not have produced its first litter, while the human being is only just beginning to walk and has not even thought about reproducing itself.' Further, in some animals sexual maturity is almost synonymous with the onset of reproduction, but in others, such as man, several years—what we term puberty—may intervene. Man is one of the few animals in which we have knowledge of life after the cessation of the reproductive cycle. Farmers and stockbreeders are not interested in prolonging the life of animals when their stud activities are over, so that reliable data concerning the duration of life in domestic animals after the cessation of reproduction are not available. There is evidence that reproductive exhaustion produces senescence in monocarpial plants and in fish, but such evidence hardly justifies the widespread human belief that sexuality has its price.

Another recurrent theory of senescence is that of the accumulation of toxic products, perhaps most vigorously expounded by Metchnikoff with his concept of intestinal poisons and the need to change the bacterial flora.

Carrel records in *Biological Time*[2] that he was able to maintain the heart of a chicken beating for twenty-five years, by immersing it in a suitable nutrient medium, which was constantly changed to avoid the accumulation of metabolites and was accurately controlled for temperature and oxygen content, and for the avoidance of bacterial contamination. Many of the theories of nutritional influences on longevity are related to the concept of the toxic effect of excessive food intake. McCay[3] has demonstrated that undernutrition will delay the growth and prolong the life of rats if the undernutrition is begun before the onset of the reproductive cycle. Undernutrition after the development of maturity did not prolong life.

The tissue changes reported by many workers—Cowdry, Lansing, the present author and his group—are certainly a feature of the aging animal, but whether they are cause or effect remains unanswered and thus does not permit of any generalization as to the mechanism of senescence.[4]

Wear and tear is probably the most popular view of the cause of senescence; but the very complexity of the human organism with its dif-

1. H.Eckstein, *Old Age in the Modern World*, Edinburg, Inter. Assoc. of Gerontology, 1955, p. 191.
2. P. Lecomte de Noüy, *Biological Time*, Foreword by A. Carrel, London, 1936; New York, 1937.
3. C. M. McCay, *Cowdry's Problem of Ageing*, Baltimore, 1952, p. 145.
4. E. V. Cowdry, *Problems of Ageing*, Baltimore, 1952; and A. I. Lansing, *Colloquia on Ageing, No. 1, General Aspects*, London, 1955.

ferent times for the attainment and for the duration of certain functions illustrates still further the difficulty of using any single test of function to assess what we mean by senescence. The only mathematical formula one can apply to the study of senescence is the actuarial life-table, which is really a measure of the likelihood of dying. Many assumptions are made in the construction of actuarial tables, i.e., that there is no allotted span of life such as the psalmist's three score years and ten, and that there are no gross differences in the human stock used in compiling the tables. Despite these and other difficulties, the actuarial tables do provide information of value both to the biologist and to the sociologist. Death in man is, in fact, accidental. There is no evidence for the view that natural death is due to the gradual atrophy of the organs until they can no longer provide the momentum for life. Vischer[1] reported the death of two centenarians who were apparently healthy right up to the onset of their terminal illnesses, yet careful examination of their organs after death revealed changes which might have led to death at any time in the previous thirty years. The experimental study of duration of life in animal colonies has been vitiated by the incidence of disease. Lack, however, has shown that the mortality of wild birds is, after the first few months, independent of their age.[2] It would thus seem that there is no evidence for the view that death is natural or that, even if we could shield man from environmental hazards both internal and external, he would survive to, say, 100 or 120 years; nor is there any other than biblical authority for selecting three score years and ten as the natural span of human life.

THE AGING POPULATIONS

The changes in the age distribution of the population have made senescence a topical problem. The discoveries of medical science have increased the life expectancy at birth. Many factors have contributed to the reduction in infant mortality, but undoubtedly one of the most important has been the development of the chemotherapeutic agents—the sulphonamides and the antibiotics. The life expectancy at birth in the United States of America was 35½ years in 1789, 40 years in 1850, 50 in 1900, 55 in 1920, 60+ in 1930, and today it is nearly 70 years. Similar changes have been reported in most of the countries of Western Europe and North America. In Switzerland in 1876-80 the expectation of life for men was 47 and for women 51. In 1929-32 it was almost 68 for men and 70 for women. In Great Britain the expectation at birth at the turn of the century was just over 50 years, while today it is 68 for men and 70 for women.

1. A. L. Vischer and F. C. Rowley, *Virchows Arch.*, 1952, *321*, p. 652.
2. D. Lack, 'Population Ecology in Birds', *Proc. tenth inter congr. onithol.*, 1951, p. 409.

Percentage of sexagenarians	*France*	*Sweden*	*England and Wales*	*Germany*	*Italy*
8	1790	1850	1910	1911	1860
10	1850	1882	1925	1925	1908
12	1875	1912	1931	1937	1952
14	1931	1940	1938	1951[1]	1964
16	1950	1955	1952	1959[1]	1972
18	1964	1965	1962	1964[1]	1988

1. Western Germany only after 1945.

Sauvy in the above table shows clearly the increase in the proportion of the population over the age of 60 in some of the Western European countries.[1] In the United States of America, Canada, Australia, New Zealand and the white population of Africa trends are similar. It is impossible to forecast beyond 1980 because we cannot accurately foretell the birth-rate. In the United Kingdom an unexpected prolongation of the customary post-war increase in the birth-rate has occurred, making it impossible to indicate anything more than trends. A position of biological equilibrium, where the birth-rate just ensures the replacement of one generation by another, with the maintenance of life expectancy at the same level as it is today, would mean that approximately 24 per cent of the population in Great Britain would be sexagenarians.

In the United Kingdom to-day approximately 14 per cent of the population are of pensionable age, that is to say, men over 65 and women over 60, or, to put it in another way, 2 out of every 15; and 1 out of every 15 is over the age of 70. In 25 years' time 3 out of every 15 will be of pensionable age, and 1 out of 9 will be over the age of 70; in other words there will be approximately 5 million people over the age of 70.

These population trends have considerable political and economic significance, since the countries with a low (2-3 per cent) proportion of aged people are the so-called underdeveloped countries, e.g. the countries of the Far East and of Eastern Europe. Similar changes are taking place in these latter countries, but at a much slower rate owing to the continuing high birth-rate. In the more developed countries—those of Western Europe and North America—the aging tendency of the population will grow rapidly even if the downward trend in the birth-rate ceased, because there is already such a large proportion of the population in middle life progressing towards old age.

Further, the advances in medical science have been effective against infectious diseases, particularly those affecting the young. The diseases of the second half of life—heart disease, renal disease, vascular degeneration,

1. A Sauvy, *Old Age in the Modern World*, Edinburgh, Inter. Assoc. of Gerontology, 1955, p. 30.

cancer—are usually insidious in onset, and it would take several years before even rapid advances in therapy could influence current trends. Ultimately, such discoveries might completely alter the age distribution of the population by enabling man to overcome the major known killing diseases and thus to live longer, 100 or more years becoming the normal expectancy.

Although life expectancy at birth has greatly increased in the last 100 years, life expectancy for the middle aged has on the other hand changed very little. In 1901-10 the expectation of life for a man aged 60 in the United Kingdom was approximately 13½ years; in 1950 it was 15 years, an increase of 1½ years. The most recent returns (1955) indicate a slightly more favourable outlook for the present day, the increase being of over 3 years instead of 1½ years. The major change, however, remains the increased expectancy at birth rather than in middle life.

THE MEDICAL PROBLEMS

The popular concept of aging is one of deterioration; old age is the period of the wig, the ear trumpet, the spectacles, the denture, the artificial leg, and the silver wind pipe. Undoubtedly many of the disabilities of advancing years result from the stresses and strains of life, and from the effects of illness. The miner is more liable to osteoarthritis of the knees than the clerk. The business executive and those in positions of authority are more liable to coronary disease, hypertension and peptic ulceration. These effects of environmental stress are becoming recognized, though we have not yet devised a satisfactory way of living to avoid their deleterious influence.

The different functions of the body do not attain their point of maximum efficiency simultaneously, nor, having attained their peak, do they lose their prowess at a constant rate. Acuity of hearing and vision attain their maximum before the age of 10, and yet it is not until the majority of adults reach the age of 50 that they require glasses for reading. By the age of 60 they are willing to move to the front of the church, the theatre or the lecture hall, their hearing being not quite what it was. In their sixties, especially their late sixties, they are aware of their lack of mobility, of their joints stiffening, and they avoid hurried movement. It is also at this age that it becomes obvious that they are shrinking in stature due to the narrowing of the intervertebral discs of the spine. In their early seventies mental changes become obvious to their friends, though not necessarily to the aged themselves.

Considerable differences of opinion exist as to the nature and extent of the mental changes which come with advancing age. It is often said that the elderly pass through a stage of second childhood when certain peculiar traits are accentuated, while many of the more pleasant features disappear. Attempts have been made to assess the changes in intelligence, perception,

memory and mental efficiency brought about by age. It has long been said that there is a marked deterioration in intelligence in old age, but recent studies would suggest that there is nothing more than a slow but steady decline from the age of 20 to 60, with a slightly increased rate of decline after 60.

Many of the tests used for children are quite unsuitable for adults, and the conclusions drawn from such tests must be treated with reservation. The question which remains unanswered is whether the rate of decline is in any way affected by the degree of attainment. In other words, is the rate of decline constant, and therefore so comparatively slight in a person of great intelligence that even at 60 he still appears to be an intellectual giant? Birren,[1] using the Wechsler Bellevue scale, felt that it was possible to assess four mental factors in the elderly and to compare the results with those obtained from younger age groups. The four factors were verbal comprehension, non-verbal organization of visual perceptual material (also called matrix test, which does not involve any writing or speech and where people have to match patterns and designs), memory, and induction. What is so difficult in all testing is the fact that memory tests are influenced by intelligence and habit patterns. The complete lack of longitudinal studies has been stressed by Lewis,[2] and until we have had extensive longitudinal studies it is dangerous to generalize about the mental changes associated with age. The Rorschach Test, which is known to have the risk of personal bias, has tended to show that features of aging are: a reduced responsiveness to emotional stimuli, an inability to use new resources, difficulty in forming satisfactory social relationships, and lessened instinctual control.

On the contrary, history is full of examples of men who have written masterpieces or performed extraordinary intellectual feats when in their late seventies and eighties. Goethe completed the second part of *Faust,* Verdi composed *Falstaff,* and Humboldt wrote *Kosmos,* when in their eighties. In the past decade, also, almost every branch of knowledge, science, music, art, literature, philosophy, and even politics, has had outstanding men who were still active and productive although nearly octogenarians. If this is an indication of trends, the outlook for the future is hopeful.

All the disabilities mentioned above would seem to be the normal lot of man, but in some men they occur sooner than in others. The effect of disease is often to hasten the development of what one must call the normal disabilities. From the medical standpoint, therefore, the increasing age of the population means that an increasing proportion of it will be limited in their capacities unless new discoveries and appliances, similar to hearing aids, glasses, dentures, enable the disabilities to be minimized, if not entirely removed. These disabilities, which may be said to be normal in old

1. T. E. Birren, *J. Cons. Psychology, 16,* p. 399.
2. A. Lewis, *Colloquia on Ageing, No. 1, General Aspects,* London, 1955, p. 38.

age, lead to the problem of the frail ambulant, when they are more severe.

There is the still more serious medical burden which results from the nature of the diseases most likely to affect the middle aged and the elderly. The prevalent diseases of the second half of life are the degenerative diseases, all forms of vascular degeneration including hypertension, coronary, artery and renal disease, cancer, chronic bronchitis, osteoarthritis, mental disorders and diabetes mellitus. All are progressive diseases for which at present we have no certain cure. Some, such as bronchitis, may be largely environmental in origin, and the removal of smoke and of the atmospheric pollution from modern industrial processes would do much to minimize, if not abolish, the condition. The disorders named above, however, tend to run protracted courses, often with recurrent periods in hospital, a high proportion of the patients ultimately becoming chronic invalids. The cost of medical care—already the most expensive of the social services—is likely to increase very considerably as the result of the altered age distribution; it may be noted that more than half the patients in the mental hospitals in Great Britain are over the age of 60.

Pneumonia, in one form or another, and bronchitis used to be very frequent causes of death in people over the age of 50. Today antibiotic therapy enables many such patients to overcome the infection; but they are left physically enfeebled and succumb readily to a further infection, often entering hospital for a period of six to eight weeks several times a year. This problem has been referred to as that of 'medicated survival'.

SOCIAL SURVEYS OF OLD AGE

Health is almost the most important asset in the life of a man. It is ill-health and the impairment of function which cause the majority of the social problems of aging. Great Britain has been the pioneer in the development of the social survey technique. Charles Booth's famous survey of life and labour in London was the first great survey of what is now called the social science field.[1] Seebohm Rowntree, by his well-known studies of the City of York[2] has contributed greatly to our knowledge of living conditions in the United Kingdom during the past 50 years; he was also chairman of the first Nuffield Foundation report, *Old People*.[3]

During the last 20 years social surveys on different aspects of the life of the community have been made in almost every country. Reference can

1. C. Booth, *Old Age Pensions and the Aged Poor*, London, 1899.
2. B. Seebohm Rowntree, *Poverty; a Study of Town Life*, London, 1901; *Poverty and Progress*, a second social survey of York, London, 1941; B. Seebohm Rowntree and G. R. Lavers, *Poverty and the Welfare State*, a third social survey of York, London, 1951.
3. *Old People*, report of a Survey Committee on the problems of aging and the care of the old people, London, Nuffield Foundation, 1947.

only be made to a few of them. The surveys by Seebohm Rowntree—three during the present century—have provided invaluable data concerning the development of the social pattern in Great Britain as regards work, housing and poverty. The last of the three surveys concluded that the two major causes of poverty in the United Kingdom in 1950 were chronic sickness—i.e. where the bread-winner was off work for more than six months on account of sickness—and old age.

Two surveys, by Dr. Sheldon, of Wolverhampton, England,[1] and by van Zonneveld of Groningen, Holland,[2] have produced valuable data on the medical and social problems of an aging community. Dr. Sheldon visited a sample of the population of Wolverhampton of pensionable age in their own homes. Wolverhampton is a town of 150,000 inhabitants situated in the centre of England, in the industrial belt. The sample was obtained by taking 1 in 30 of all the ration cards—at the time of the survey rationing was in force in Great Britain and provided a valuable register of the population. From this sample the names and addresses of men over the age of 65 and women over the age of 60 were selected. The sample comprised 593 individuals; for 552 of them a complete form concerning the social history was obtained, and Dr. Sheldon was able to complete the medical enquiry in 477 cases.

Rather less than a third (29 per cent) were receiving medical attention at the time of the survey, and more than a third (44.2 per cent) had received medical attention during the previous three years. The assessment of the physical state revealed that malnutrition was uncommon: 24.5 per cent of the group were classified as normal plus, 46.2 per cent as normal, and 29 per cent as subnormal. These figures relate to an overall assessment and mask an important difference between the sexes. The men were more active and contained a significantly higher proportion of those who were in the normal plus group; in fact, the men seemed to fall more into the extreme groups than did the women; the majority of the women had some disability, although not necessarily a severe one.

Sheldon comments on the different medical problems that arise after the age of 70. Up to 70 the prevalent illnesses and disabilities are those which are the common lot of man, but after 70, weakness, vertigo, spondylitis, difficulty in facing traffic and loss of confidence become increasingly prevalent and affect most profoundly the life and movement of this age group.

Reverting to the group of men over 65 and women over 60, 2.5 per cent of the sample were confined to bed, 8.5 per cent were confined to their own homes, and 22.5 per cent has limited mobility, being able to walk only to the end of the street. A third of the sample therefore was

1. J. H. Sheldon, *The Social Medicine of Old Age*, London, Nuffield Foundation, 1948.
2. R. J. van Zonneveld, *Old Age in the Modern World*, Edinburgh, Inter. Assoc. of Gerontology, 1955, p. 349.

severely restricted in mobility. A further analysis of the figures into the different five-year age periods demonstrated an even more marked increase in the percentage of individuals suffering from restricted movement after the age of 70. There were, of course, many factors contributing to the impaired power of locomotion, such as defective vision and pain in the feet. The latter could often have been cured by chiropody, which would have considerably increased the possibilities of a fuller life.

The mental state was classified as normal in 81.8 per cent of cases and only slightly impaired in a further 11.2 per cent, the remainder being divided almost equally into those who were difficult to live with, and those in whom there was evidence of mental disorder.

The incidence of sickness amongst elderly persons living in their own homes is considerable. Sheldon found that more than half of the group had experienced, after the age of 60, illness requiring a period of rest in bed. Most of the married men were nursed by their wives, whereas the women were dependent on the help of a neighbour or relative. Sickness amongst the women interfered more seriously with family life than did sickness amongst the men, and often necessitated the absence from work of a daughter or near relative, or the making of demands upon the statutory services. Periods in bed, if prolonged, or for other than minor illnesses, place great strain on otherwise independent couples, who manage together for everyday things so long as there is no sickness. In 7.7 per cent of the sample the physical burden of sickness was assessed as causing a severe physical stress on the next generation. In a further 15 per cent, sickness interfered considerably with the lives of near relatives, often to the extent of preventing them from getting away and even of spending their holidays with their own family.

Van Zonneveld carried out a similar survey in Holland at Groningen, a town of 140,000 inhabitants and reached almost identical conclusions. Once again there was a higher proportion of women in the group with a moderate degree of impairment of health. Some 40 per cent of the sample group were in receipt of medical treatment at the time of the inquiry or in the three months prior to the onset of the survey. Ignoring the personal opinions and the material circumstances of the group, Zonneveld estimated that for every 1,000 of the population over 65, 4.3 required accommodation in hospital, 34 in special nursing homes or mental institutions, and 153 in residential homes.

A recent survey in Sheffield, England, a large industrial city of over 500,000 inhabitants, by Hobson and others,[1] added few fresh data to those already obtained from the excellent surveys by Sheldon and van Zonneveld, except that the former were able to undertake physical examinations and to obtain from the participants blood and other samples for laboratory investiga-

1. W. Hobson *et al.*, *Old Age in the Modern World*, Edinburgh, Inter. Assoc. of Gerontology, 1955, p. 349.

tions. In the Sheffield survey 40 per cent were receiving regular medical attention at least once every three months. The percentages of bed-ridden, confined to home, and with limited outside activities were very similar to Sheldon's findings. One of the most interesting features of the survey was the discrepancy between the patient's and the physician's estimate of fitness. The physician found that 26.2 per cent of the men could be considered fit, as opposed to the men's personal estimate of 64.1 per cent. In the case of the women, the physician estimated that 23 per cent were fit, whereas 48.7 per cent of the women considered themselves so.

Dr. van Zonneveld is now engaged in organizing a complete survey of the elderly population in Holland, co-operating with the family doctors. This thorough and important social survey will also include a careful survey of mental health.

Sheldon found that in Wolverhampton 98 per cent of all old people lived at home and only 2 per cent in institutions. The latter percentage is today probably an underestimate. Of the people living at home, 44 per cent were married, a third of them living without and the other two-thirds with their children. Another 44 per cent were either widows of widowers, the latter tending to live with relatives, whilst the former lived in their own homes. It is of interest that more than half of those living alone had children or near relatives living either next door, within a short distance, or who visited regularly.

THE SOCIAL AND ECONOMIC PROBLEM

The analysis of the health of an aging population in the middle of the twentieth century reveals the extent to which ill-health and disability increase the dependence of the elderly upon the family, or upon the community, be it good neighbours or the state. The fundamental problem, as already stated, is not new; but the changing social pattern and the increasing number of individuals involved are necessitating a different approach. The changing concept of family life is throwing more responsibility upon the community, whether it be the voluntary or the statutory authorities.

In an underdeveloped and rural community, the centre of social life is the family. Several familes may unite in a common task, such as farming or fishing; such communities will remain small, comparatively self-contained, and with the family atmosphere dominant. They will share a common mode of life and common culture, and even in the next stage of development the head man or leader will still assume a paternal position of authority in relationship to the group. Such a family group must utilize the skills and abilities of all its members, so that work is required from both young and old, according to their skill and capacity. There will be variety of company

for the elderly, and the doting grandparent to comfort the disappointed child. Such a community will not be able to understand the problems of pensions and taxes and of divided responsibility.

The advent of the industrial age altered the life of the communities, both geographically by demanding greater mobility of labour, and also culturally because the members of the family often followed different trades and occupations. Furthermore the scattering of the family lessened the paternal authority of the home and accentuated the individuality of the different members. The development of wealth, centred upon minerals and manufactured articles, necessitated new methods for safeguarding estate and property other than land. The result was the development of insurance to provide security for the individual and his dependents against the hazards of life. The diminishing size of the family has accentuated the loneliness, sense of insecurity, feeling of uselessness and of dependence that were already evident in the early industrial period, and has led to the present phase of organized society, commonly referred to as the welfare state. It would be wrong, however, to assume that loneliness, insecurity, a feeling of unwantedness and dependence amongst the elderly are something new that did not exist in primitive communities; it is rather that the evolution of the social pattern, through the breaking up of the family, has accentuated these difficulties.

Disability and ill-health amongst the aging members of a community obviously affect its productive capacity and therefore its ability to maintain its standards of living. Present population trends in Western Europe indicate that the percentage of dependents—children under 15 and adults over 65—is likely to remain constant during the next 20 years, the decrease in the percentage of children under 15 being counterbalanced by an increase in the percentage of adults over the age of 65. The economic problem is whether it will prove more costly to maintain the elderly than to rear the young. If full activity could be maintained despite increasing years, no problems would arise. Increased productivity could likewise counterbalance the cost of maintenance of the elderly, so that undue despondency concerning the economic position may prove unjustified.

The needs of the elderly in modern society have been met in two ways—by the provision of pensions or by relief funds, dispensed either by voluntary charitable organizations or by governmental agencies. Pensions are of two kinds: the voluntary schemes subscribed to by individuals or firms on behalf of their employees, and those provided by state departments and state insurance schemes. Individuals enter into agreement with insurance companies, the policies really forming a variant of normal life assurance. Many firms now have schemes to cover their administrative, clerical, and skilled staff, and a few firms cover all grades of staff. Such schemes are in the main financed by the firm, the employee making some contribution in the majority

of cases. In state departments a percentage of the salaries is deducted yearly, and pensions are usually based on the income during the last few years before retirement and on the length of service.

State insurance pension schemes for all citizens usually provide for a flat rate of benefit for all persons fully insured on the attainment of a fixed age, on condition that they are not earning more than a certain amount per week or per month and have no private savings in excess of a stated amount. These pensions are often looked upon as a right, although they are more in the nature of insured relief and are provided by contributions from the employee, the employer and the state. The amount of the pension varies considerably in different countries, and in the past, rates have normally been below the minimum wage that could be earned by an unskilled worker, so that the pension should not be an inducement to idleness. In recent years some countries have adopted the principle that need should determine the rate of pension. Lord Beveridge, in his report on Social Insurance and Allied Services 1942, advocated this principle, and his idea has been largely incorporated into recent British legislation.

That need exists has been shown by the analysis of incomes of the elderly. Estimates of the incomes in 1949 in the United States of America showed the average yearly incomes in the different age groups as follows: 35-44, $2,591; 45-54, $2,751; 55-64, $2,366; and 65 plus, $1,016. The Federal Security Agency enquired into the source of income of 11.5 million individuals over 65 in 1949 and found the sources of income to be as follows:

	Individuals	*Per cent*
Employment	3.8 millions	33
Social insurance and related programmes	3 millions	26.1
Old age assistance	2.1 millions	18.3
Other sources, including no income	2.6 millions	22.6

The Institute of Life Insurance in 1950 listed sources of income for persons over 65 as follows:

	Per cent
Employment	34
Pensions	18
Private assistance	17
Investments	9
Public assistance	22

Further analysis by the Federal Security Agency, using a different method of computation (spending units), revealed that approximately 75 per cent of persons over 65 had no income from investments or work, and that 28 per cent received no pension or allowance. Thus, even in a wealthy country such as the United States, a considerable proportion of the population over 65 are unable to support themselves or are without relatives to provide for them.

The pensions schemes have to be supplemented by public or national assistance.

In Switzerland there is a national pensions scheme, the Federal Old Age and Survivors Insurance, which came into force in 1948, but full annuities will not be available until 1968. The rates are low, 720 to 1,700 Swiss francs per annum for a single person, 1,160 to 2,720 Swiss francs for a married couple. Single men or women can draw their pensions at 65; married couples get the full pension when the husband reaches 65, and the wife 60. Supplementary pensions and assistance are however necessary, and these are the responsibility of the cantons.

In Denmark the social insurance scheme is a mixture of insurance and national assistance. The benefit for a married couple is approximately 45 per cent of an unskilled worker's wage in Copenhagen. Some 60 per cent of the population eligible are in receipt of such pensions. In the United Kingdom the position is very similar. Approximately 60 per cent of all persons eligible on account of age draw their pension, and over the age of 70 approximately one half require supplementing from the National Assistance Board.

It will be seen therefore that in all the countries considered the existing pensions schemes are inadequate to meet the financial needs of the elderly. Furthermore, private pensions schemes, although more likely to be related to the retiring salary of the participant, depend for their real value on the maintenance of a constant value of the currency. In times of monetary stability such schemes are excellent, but during periods of inflation they are inadequate.

How to adjust pensions to provide reasonable financial security for everyone is a major problem of the welfare state. The enormous financial burden of an adequate pensions scheme for everyone after the age of 65 raises therefore the question of employment for the elderly.

EMPLOYMENT OF THE ELDERLY

Until the last war unemployment was a serious feature of the life of industrialized countries. The guilds, and later the unions, tried to combat unemployment by restrictive practices, a fixed rate for a fixed job, by delaying the age of entry and fixing a retiring age. There was also the fear that the older workers might work for lower rates, their needs being more modest. The introduction of pensions schemes has had the effect of increasing the frequency of retirement at a certain age. Retirement at 65 is four times greater in firms with pensions schemes than in those without such schemes. Further, smaller firms tend to retain the services of workers beyond the retiring age more than do the larger firms, i.e. the firms employing more than 500 workers. Compulsory retirement at a specific age has administrative

advantages. It is uniform in application and easy to administer, enables management to plan ahead and to anticipate replacements, and enables the worker to prepare for retirement and to make alternative arrangements. Another reason for the tendency to fix a retirement age is related to the problem of promotion. The younger employees of a firm often feel frustrated if there is not a reasonable opportunity for promotion, and retaining employees beyond the normal retiring age undoubtedly interferes with promotion. Union opinion is sensitive in this matter as the unions tend to lay great stress upon seniority. In the management of their own affairs, the unions before World War II tended to demand that their executive officers retired at 60, or in some cases even at 55.

The heavy cost of pensions—which is likely to increase in Western Europe because of the aging of the population—is an economic reason for recommending abolition of a fixed age for retirement. Other factors must however be considered. For instance, would postponement of retirement be in the interests of the health of the individual? Is it fair and reasonable that a man should work until he drops? Does the capacity for work diminish with age? Does this capacity for work depend upon the nature of the work? Should there be different grades and different hours of work for the older employee?

Analysis of the length of unemployment periods in the different age groups, both in the United States and in the United Kingdom, show these periods to be longest in the 55-64 age group and the 65 plus age groups. Pension schemes here have an adverse influence because insurance companies usually demand a higher premium for older workers; workmen's compensation rates are also usually higher for the elderly. It is often stated that the older workers are less efficient, less adjustable to new ideas, and more difficult to train, and that they have a higher accident and sickness rate. These comments from employers are misleading and are not entirely borne out in practice, since most firms like to retain their elderly skilled craftsmen. Experience gained during World War II, when labour was at a premium, and also the findings of the University of Illinois survey, revealed that absenteeism was less amongst the older workers. Although their rate of work was slower than that of the younger age groups, they were more reliable; the numbers of articles rejected were smaller, and the damage to instruments and machines much less than with younger workers. The sickness rate for minor illnesses of less than five days was lower than for the younger age groups, though there was a greater incidence of long-term chronic illnesses which often necessitated a few of the older workers being absent for long periods, thus making the overall loss of time for sickness greater than in the younger age groups.

Le Gros Clark[1] has recently analysed the age of men employed in 32 oc-

1. F. le Gros Clark and Agnes C. Dunne, *Ageing in Industry*, London, Nuffield Foundation, 1955.

cupations in Great Britain, involving 4,004,700 men, or 25.6 per cent of the total males occupied. The number of men over 65 in these occupations was 17,400, or 25 per cent of the national total of occupied males over the age of 65. Using 'survival rates'—the percentage of the total numbers of men known to have reached their mid-sixties and still at work in their normal job, maintaining a reasonable degree of efficiency—Clark was able to compare employment rates of the elderly in the different trades. The results were influenced by the introduction of pensions schemes, by changes in the manufacturing process, and by changes in market and consumer demands. Clark concludes that a considerable number of workers today will have to be found alternative jobs in their early or mid-sixties if they are not to be forced into premature retirement. There is evidence that some men are already making this transition to lighter and less exacting work, often within their own industry. Reviewing the results collectively, Clark estimates that 30-40 per cent of the men could not be expected to carry on with their normal jobs after their mid-sixties, and that alternative work would have to be found for them if they were not to retire. He assumes that 10 per cent would be in such a state of impaired health that no question of any work would arise, but provision would be necessary for at least 20 per cent. In 1951, the year of the analysis, there were 2,072,100 men in the age group 55-64 in the United Kingdom. This would mean that 400,000 would require alternative employment over a period of ten years, or 40,000 a year.

This raises the problem of the type of alternative work to reserve for the elderly and of the question of training for alternative work. Experience in the placement of disabled persons, and the introduction of a quota system where all employers must employ a certain percentage of disabled persons, have shown that such methods do not solve the problem. Firms would naturally reserve the special appointments for their own staff and would not readily take on elderly staff who had not previously been employed by them.

A special experimental unit sponsored by the Nuffield Foundation in the University of Cambridge, England, under the direction of Sir Frederick Bartlett and A. T. Welford,[1] have been studying experimentally the effect of age on skill. They have concentrated on the earlier age groups, 45-65, with a view to determining trends rather than to solving the problem of the 65 plus group alone. They found that there is a slowing of skilled actions in the late twenties, followed by a considerable degree of recovery; then there comes a return of the slowing in the late thirties and middle forties, followed by a further period of improvement, before the onset of a more progressive slowing in the middle or late fifties. These conclusions apply to rapid skilled work not involving heavy muscular effort. Where moderate or heavy muscular work is involved, there is a marked decline after the middle forties.

1. A. T. Welford, *Skill and Age*, London, Nuffield Foundation, 1950.

The changes described are not so much in the effector as in the receptor mechanisms. An analysis of the processes shows that the most variable element in any skill requiring a series of accurate adjustments to changing stimuli is in the interval between an adjustment in one direction followed by an adjustment in another direction. Older people look more carefully at what they are doing and at the signals necessary for the next stage. They are therefore suited for work demanding a high degree of accuracy, especially if they are able to work at their own pace, but are much less suited for belt work or processes where the rate tends to be geared to suit the younger worker. Welford and others have also found that older people are less receptive to theoretical instruction. They often prefer written instructions which they can study at their leisure rather than group demonstrations. They learn new processes which are based on their past experience with comparative ease, but are much slower in adapting themselves to fundamentally new or different ideas. It is necessary to break down a new process into component movements, which allow the elderly person to build up the process more slowly. Younger people seem to exhibit less delay in anticipating the next move. These valuable experiments indicate the complexity of the problems; yet they offer hope that, with further development and extension of the study to job analysis in industry, it should be possible to find suitable employment for the elderly.

But apart from the economic implications which employment of the elderly has for society, there is the importance of employment to the individual himself. Undoubtedly many men and women continue working after reaching retirement age because of financial need. To many, work is purely a means of earning enough to live, the work itself being without interest. But the fact that the proportion of the self-employed and the skilled craftsmen who remain at work until well into their seventies is higher than in other categories of workers shows that they have more than a mere financial interest. Work is an important factor in their lives; it affords a means of self-expression and makes them feel that they are useful to society. Retirement is a serious break for most men. It means loss of invaluable associations, it brings a feeling of unwantedness, of dependence on, and uselessness to, the community. For the man with few interests, retirement often means that his world suddenly becomes very limited.

ACCOMMODATION FOR THE ELDERLY

Another important problem for the aged is accommodation. Many people save, often at great personal cost, for their retirement. They select a site, quite likely build a house—but how rarely do they anticipate their real accommodation needs? The ancient guilds, and later the philanthropists of

the sixteenth to the nineteenth century, endowed special buildings for the elderly and poor of their craft or their town. In Great Britain such accommodation was called an almshouse, and there are still some 12,500 inhabited almshouses in Great Britain. Many now require modernization, but they were usually well sited in the centre of the community, near the church and shops, and undoubtedly went far towards meeting the special housing needs of the elderly in Great Britain until the beginning of the nineteenth century. The survey at Wolverhampton by Sheldon emphasized some of the physical problems of the elderly, their dislike of stairs, their tendency to falls, and their immobility. The elderly adapt slowly to changes of light intensity, and therefore require good and even lighting. They also like warmth, and the provision of central heating is desirable in accommodation specially designed for them.

Many countries have paid special attention to the designing of houses, bungalows, and flats for the elderly. Such special accommodation should be planned in small groups, preferably not in isolated communities, so that normal housing which permits young relatives to live within easy access is near at hand. The amount of special accommodation for the elderly is nothing like adequate. In Great Britain between the two wars over 3,150,000 houses were built—1,440,347 by local government and the remainder by individuals or private firms; yet only approximately 1 per cent of all this building was specially designed for the elderly. Immediately after the war the building programme concentrated upon houses suitable for young married couples with children, and very little accommodation for the elderly was constructed. This is now being corrected, but there is considerable leeway to make up. Some 5-7 per cent of all new building in Great Britain during the next 10 years would need to be allocated to old people if the majority of them are to be housed in suitable accommodation. Owing to the post-war building difficulties, special grants are available for the conversion of old houses, but many old people are unable to afford their share of the cost and they are also afraid to leave their present houses because of the higher rents of newer accommodation. The need for adequate housing of the elderly is vital because the added strain of living in unsuitable accommodation may precipitate disability and dependency.

It is recognized that there is a stage at which the elderly, though they may be able to dress and attend to personal details, are unable to look after themselves; yet they do not require nursing or hospital care. The Salvation Army was the first organization to provide accommodation for this category when they established their first Eventide Home in Norway in 1910. In Great Britain today there are nearly 2,000 homes, or hostels, caring for nearly 60,000 elderly people. One-third are run by voluntary organizations and two-thirds by local government. The majority house 30-35 elderly persons, usually of one sex only, although an increasing number are being planned

for both men and women. In Switzerland 25,000 persons over the age of 65 are living in public or private hostels. In the United States 217,000 persons over the age of 65 are housed in public or private institutions primarily designed for the aged. Accommodation of this kind is undoubtedly necessary, especially nowadays when families are small and such a high percentage of the frail ambulant individuals are without relatives.

Collective homes and hostels, however, do not afford the ideal solution. Transference to such homes affords security and, for many, eases the loneliness of old age. On the other hand, for those with active minds and wide interests, this kind of home can have a restricting influence, and limited contacts with the outside world often makes the inmates uninterested, quarrelsome and unhappy. The aim when providing accommodation for the elderly should be, whenever possible, to maintain the elderly in their own homes. Grouping of bungalows or flats so that a warden can be appointed to keep an eye upon a group of elderly persons and, if necessary, to provide a midday meal, is not only valuable in allowing the elderly person to remain a member of the community, but is often a more economical way of solving the problem of care of the elderly.

The provision of domiciliary services can do much to help the elderly, particularly the frail, to retain and live in their own homes. Many voluntary and charitable organizations, the Churches, and Government Departments play an important role in this respect. The extent of the help varies according to districts and to needs. It may include special nursing, the provision of special apparatus, the adaptation of the household fittings to special needs, laundry service, a meals service. In addition, a visiting service is often arranged. It may consist merely of a regular friendly call, but may extend to reading to the old person, looking after the garden, undertaking shopping expeditions, the writing of letters, a 'pots and pans' service, and occasionally to the provision of more comprehensive help—the so-called Home Help Service. Special services, such as chiropody and physiotherapy, are also organized for old people in their homes. For the more active, the club movement with its discussion groups, hobbies, talks, competitions, provides the opportunity to make friends, and minimizes the extreme loneliness, which is probably the greatest single problem of the elderly today. A certain degree of dependence and an inability to contribute actively to the life of the community can only accentuate the gravity of this problem.

Medical care is the most expensive of the social services, and the high proportion of the elderly who require hospital attention both for mental and physical illness provides the hospital administrator with his biggest and most costly problem. Special units, called geriatric units, are being developed in the Scandinavian countries, in Great Britain, and the United States to foster a more progressive and active attitude of mind towards the care of the chronic elderly sick.

CONCLUSION

The increasing proportion of the elderly and the diminishing proportion of children are creating a new form of society in the countries of Western Europe and North America. By 1980 the over-sixties in Sweden and Great Britain will constitute nearly one-third of the voting power. If intellectual, emotional and personality changes are a feature of increasing years, what is to be the pattern of society? Such thoughts suggest that a study of those who appear to have achieved a successful old age is essential. Undoubtedly a man with many and wide interests and with the full retention of his faculties is the one most likely to achieve a successful old age. In the United States much thought has been given to preparing people for old age and to advise for retirement. Other countries are following the American lead, and there would certainly seem to be a place for such programmes. If senescence is a biological process, it may be necessary to devise a new pattern of living, responsibility and leadership being confined to the period of peak performance, with subsequent adjustments for the later years.

The advances of medical science have led to a marked increase in the expectancy of life at birth, particularly in the countries of Western Europe and North America. Medical science has not yet solved the problem of senescence. Many of the disabilities associated with aging are the result of disease, so that it is impossible as yet to answer the fundamental biological problem.

The magnitude of the medico-social problem, however, demands the provision of an increasing proportion of national and international resources for research on aging and into the causes of the degenerative diseases which contribute so largely to the frailty of the aged. Lack of health, mental and physical, is the major cause of the disabilities attributed to aging.

A full and immediate understanding of the sociological factors consequent upon a decline of the physical and mental processes due to aging is essential if the elderly are to be incorporated into the life of an aging society instead of being rejected. Rejection could only lead to a complete disruption of community life.

To sum up: aging therefore has scientific, economic, social and political significance for the community as well as for the individual, and—with all its ramifications—justifies consideration as a major biological problem of the second half of the twentieth century.

THE IMPACT OF VIRUSES ON SOCIETY

by
F. C. BAWDEN

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There is hardly any need to stress the impact of viruses on society. The names of only a few of the better known diseases they cause in man are in themselves a sufficient argument; poliomyelitis, yellow fever, smallpox, measles, rabies, influenza and the common cold serve well enough to show that viruses are responsible for some of the most prevalent and most feared diseases. As they also cause many of the epidemic diseases of children, an adult who has not personally suffered from at least one virus would be a remarkable phenomenon.

But their direct effect on human health and happiness is only one way in which viruses influence human affairs. Annually they cause immense losses of farm animals and crops; for almost every kind of organism, from the largest to the smallest, has its serious virus diseases. To catalogue these in any detail would be only tedious; no more need be said here than that, in animals, they range from foot-and-mouth disease of cattle and myxomatosis of rabbits, to the polyhedral diseases of silk-worms and other insects; and, in plants, from the many infectious chloroses and degeneration diseases of trees and other flowering plants to the killing of the smallest bacteria.

DEFINITION OF VIRUS DISEASE

Known virus diseases look an oddly heterogeneous collection, with little reason at first sight for them to be grouped together. What has influenza in common with, say, a mosaic disease of tobacco plants, or yellow fever with an infection that decreases the yield of potato crops? The answer lies in the fact that the causes of all these diseases have two features in common, features that are both essentially negative. The first is invisibility, for none of these diseases has a cause large enough to be seen through ordinary microscopes that use visible light. The second is, to use pathologist's jargon, that the causes are all obligate parasites, which means that, although they

multiply readily enough in susceptible living cells, none has yet been made to grow in an artificial medium.

The difference between viruses and other causes of diseases can perhaps be most simply demonstrated by briefly considering the history of pathology, and the changes of usage the word virus has undergone. The idea that some diseases are infectious, that is to say, have causes (contagions) that spread from one individual to another, is age-old, but sharp distinctions between infectious and non-infectious diseases are relatively recent, as are clear ideas about the nature of contagions. Diseases were for ages regarded either as effects of adverse environments or as divine punishments about which little could be done except to try and appease the angry Gods.

Although it was early appreciated that microbes always accompany certain diseases, the belief that one kind of organism could generate spontaneously from another was for long so firmly established that the microbes were unquestioningly accepted as products of the diseases. In the first half of the nineteenth century a few botanists were bold enough to suggest that some fungi were the causes and not the products of diseases, but until Pasteur's dramatic exposure of the fallacies of spontaneous generation, they were lone voices crying in the wilderness. After Pasteur's work had firmly established the germ theory of disease, the previous supine attitude towards diseases disappeared. There was an immediate reaction against the earlier mystical beliefs, and for a period it was confidently thought that, for every different disease, a given micro-organism would be isolated and identified under the microscope or by its growth in a culture medium.

The period was brief, for the problem was to prove much more complex than this. Not all diseases are infectious; some result from dietary deficiencies or poisons, which are not transmitted from one individual to another. Also, it soon came to be doubted whether all infectious diseases are caused by visible micro-organisms. Pasteur himself could identify no obvious microbe as the cause of rabies. In 1889 he wrote ' . . . virulent affections are caused by small microscopic beings which are called microbes. The anthrax of cattle is produced by a microbe. . . . The microbe of rabies has not been isolated as yet, but judging by analogy, we must believe in its existence. To resume: every virus is a microbe. Although these beings are of infinite smallness, the conditions of their life and propagation are subject to the same general laws which regulate the birth and multiplication of the higher animal and vegetable beings.'[1]

It is worth noting that Pasteur used the word virus as synonymous with microbe. The literal translation of the original Latin word seems to be poison or toxin, so his usage was itself a considerable change in meaning. The semantic changes could be a cause of considerable confusion. Pathologists

1. 'Rabies', The New Review, No. 6, Nov. 1889.

seem never to have used the word virus in its original restrictive sense. Before the germ theory was accepted, it was used generally to cover the cause of any sort of disease. Afterwards, it became restricted, but, oddly enough, so that it was applied only to infectious diseases. First, it was a synonym for microbe, as used by Pasteur, but then, as pathogenic microbes came increasingly to be placed in different groups under their own names—bacteria, fungi, protozoa, and so on—so the word virus became less and less used in this way and was more and more applied to the cause of infectious diseases for which no organism had been recognized. Virtually the name was a cloak for ignorance, which, it must be confessed, to some extent it still remains today.

The first substantial reason for separating what are now called viruses from other kinds of pathogens was discovered in 1892. Tobacco plants were then shown to contract mosaic when inoculated with the seemingly sterile fluid obtained when juice from diseased plants was passed through filters which retained the smallest bacteria. In 1898 the cause of foot-and-mouth disease of cattle was also shown to pass through bacteria-proof filters. After this, the adjective 'filterable' was generally applied to viruses, to point the contrast between them and other microbes; but as usage increasingly restricted the word virus to the obscure entities which had this property of being 'filterable', the adjective became redundant and was abandoned.

THE NATURE OF VIRUSES

The ability of viruses to pass through bacteria-proof filters is, of course, due to the fact that they are small; it has no more significance in defining their nature than has their invisibility under the microscope. About many viruses we still know nothing directly, and their existence is recognized solely because of the diseases they cause. They obviously multiply when in susceptible organisms, and it is also clear that, in doing so, they sometimes produce new forms that differ from the parent type by causing a disease with recognizably different symptoms. The ability to multiply and to change is usually considered a property characteristic of living organisms, and when the only difference known between viruses and bacteria was that viruses were smaller and did not multiply except in living cells, it is not surprising that they were generally considered to be sub-microscopic organisms. Indeed, there are pathologists who hold this view today, even though there is much evidence that conflicts with it.

One difficulty in attempting to generalize about viruses is that there is no conclusive evidence that the many agents now grouped under the name are all the same kind of entity. Certainly none of them fits into any of the other major categories previously distinguished by biologists, but this is an insuf-

ficient reason for assuming that they constitute a uniform category of their own. However, those that have been studied in any detail do resemble one another by combining properties that are usually considered characteristic of categories as different as organisms and molecules. In size they bridge the gap between the two categories, and their uncertain biological status and evolutionary significance have excited interest and provoked controversy ever since they were first discovered.

But we are not concerned here with arguments for or against any particular view about the position of viruses in the biological hierarchy; perhaps it would be more useful to stress that there is no need to assume either a similar evolution for all viruses or that all must necessarily resemble in composition those about which we do know something. There is evidence enough that, although each kind of virus has particles of a characteristic shape and size, different viruses have particles of greatly different sizes. Some approximate to the size of the smallest bacteria and are almost large enough to be seen with ordinary microscopes; others are much smaller—no larger than the particles of many proteins that are normal components of cells and that would usually be described by chemists as substances.

Away from the organisms in which they multiply, viruses also behave rather like substances, for they appear to be quite inert and to have no independent metabolic activities. Some of them are stable and, by using methods of the protein chemist, they have been isolated in apparently homogeneous states and their constitution determined. Most work of this kind has been done with the smaller plant viruses, several of which have been prepared in characteristic crystalline forms, and these have been found to contain only two components, protein and nucleic acid, combined in a regular structure to give uniform particles.

This simplicity and regularity of structure contrasts strikingly with the constitution of even the simplest bacterium, which contains, not only proteins and nucleic acids—and these occur both separately and combined in different ways—but a wealth of other substances, such as fats, carbohydrates and diffusible organic and inorganic compounds. Bacteria, too, are richly endowed with a range of enzymes capable of making many different kinds of chemical change, few or none of which seem to fall within the power of these purified viruses.

All viruses may not be chemically as simple as the crystallizable ones from plants, but there is no reason to think that these simple ones are exceptional; on the contrary, because the few others whose compositions have been studied at all critically have also been found to consist predominantly, if not exclusively, of protein and nucleic acid. The constitution of many viruses is something that is unlikely to be discovered for a long time yet, because the work presents great difficulties. The problem is relatively simple with a virus that reaches a high concentration in infected cells and that is also stable

when extracted from its host cells, but many have neither of these qualities. To free unstable viruses from all other materials present in cell extracts, and then to get the purified virus in quantities large enough to be weighed and analysed, has been made easier than it was by the development of high-speed centrifuges in which viruses can be sedimented from solutions; but even so it remains a formidable problem.

The fact that a fluid can be diluted a million times and still be infective may seem to imply that it contains a lot of virus, but this is not necessarily so. Viruses are extremely small things, and a million particles of some weigh no more than 0.0000000001 gram; to get an appreciable weight, then, thousands of millions of particles are needed. Knowledge about the composition of viruses, therefore, is mainly restricted to those that multiply extensively in infected cells. Some do reach remarkably large amounts, and become major constituents of infected cells. From a kilogram of fresh tobacco leaf, for example, as much as 10 grams of tobacco mosaic virus can be isolated, and this virus can amount to as much as half or more of the total soluble protein of infected plants. Because it is stable and can be produced in large amounts, far more is known about it than about any other virus and about most other proteins. There are complete analyses showing, not only the ratio of nucleic acid to protein, but also the relative proportions of every aminoacid contained in the protein part and of every purine and pyrimidine in the nucleic acid. Detailed analyses, made on variants of the virus, which differ from one another by causing diseases of different type or severity, show that some variants contain characteristic amounts of certains aminoacids, and that an individual aminoacid may occur in one variant but not in another.

We are still far from knowing what changes in composition affect virulence and other biological activities, but the first steps are now being taken to get this information, and further advances can soon be expected. Explanations for biological variability may well come from further work on this mosaic virus, for it is already clear that, when it multiplies, the result is not a single uniform product that exactly resembles the initial infecting particle, but a range of similar products not all of which are infectious. There is no such detailed information about any other virus, but it is becoming increasingly apparent that several—which infect organisms ranging from man to bacteria —resemble it, not only by being nucleoproteins, but also in some other respects, even though their particles are bigger and differently shaped. Until there is some evidence that other viruses differ fundamentally from tobacco mosaic virus, the most profitable course, therefore, is to assume some uniformity, and to argue by analogy and extrapolation from the ones that are easiest to study.

Fortunately, finding the size and shape of virus particles is now a much simpler task than finding their chemical constitution; one reason for this is

that it can be done with dilute and impure virus preparations. It has become possible because microscopes have been developed in which beams of electrons replace the beams of visible light used in conventional microscopes. The resolving power of ordinary microscopes is limited by the wavelength of light, and because beams of electrons have shorter wavelengths than visible light, electron microscopes can resolve much smaller particles. Even the smallest plant viruses can be resolved and photographed, and the pictures obtained have not only confirmed the earlier conclusions that each virus has particles of a characteristic size, but have shown that different viruses also have particles of very different shapes.

Many of the small plant viruses have uniformly spherical particles; others are greatly elongated, some appearing to be rigid rods, and some flexible filaments. Some of the bacteriophages (viruses that destroy bacteria) have more interesting shapes; they have quite long tails and closely resemble minute tadpoles. Despite their greater morphological complexity, however, they resemble the smaller plant viruses in consisting of protein and nucleic acid. The nucleic acid seems to be carried in the head of the tadpole, where it is surrounded by a protein coat. This again may not be exceptional, for there is evidence that the nucleic acid may also be carried centrally in some of the plant viruses.

Most of the viruses that attack animals seem to be spherical or nearly so, but influenza virus sometimes occurs as filamentous threads. Pictures of some of the largest viruses, from both plants and animals, suggest that they may be bounded by a membrane; their composition is unknown and it is worth repeating that they may be chemically more complex or even quite different from the smaller viruses. However, we can summarize present knowledge and thought by saying that everyone expects them to contain protein and nucleic acid, and it will be a discovery of considerable biological and practical significance if any virus is shown to have any other component that is essential for its ability to infect susceptible cells.

In their general structure and constitution viruses resemble individual parts of cells rather than whole cells, and their ability to reproduce themselves is closely paralleled by other components of cells that are also thought to be nucleoproteins. Prime among these are the chromosomes, which are contained in the nucleus and are the bearers of most inherited characters, but there are also genetic determinants and other particles in the cytoplasm that have somewhat comparable capabilities. The nucleic acid characteristic of chromosomes, called desoxynucleic acid, differs from that characteristic of the cytoplasm, called ribose-nucleic acid; some viruses contain one type of nucleic acid and some the other. Thus, the nearest relatives of viruses seem to be, not bacteria or other kinds of pathogenic micro-organisms, but the nucleoproteins that occur in every kind of cell and that confer on these cells their inherited characters.

HYGIENE AND ANTIBIOTICS

To discuss the composition of viruses and to contrast them with bacteria may seem an academic matter with little or no practical significance, but this is far from being true. The fact that they differ fundamentally from bacteria may well be the main reason why they have become increasingly important, relative to bacteria, over the last 100 years. With the establishment of the germ theory of disease, the origins of many epidemic diseases became immediately obvious as bacteria that breed in all kinds of refuse and contaminate drink and food. This realization started an era when standards of sanitation and hygiene were increasingly improved; consequently, over more and more of the world many diseases that used to be epidemic have been virtually eliminated. This increased cleanliness, by extending the average length of life for human beings, has, perhaps more than any other single event, been responsible for the unprecedented speed with which populations have grown. Improved sanitation and even antiseptic treatments, however, left most virus diseases unaffected, for viruses are obligate parasites and do not breed in sewage and refuse. Indeed, there is one virus disease, poliomyelitis, which appears to be most prevalent in countries where sanitation and hygiene reach the highest standards.

Following in the wake of the germ theory, steadily increasing effort was also put into finding substances that would kill microbes without harming human beings. The search for cures was remarkably successful, culminating in the range of sulpha drugs and antibiotics that today so dramatically cure diseases like pneumonia which were not controlled by the introduction of good sanitation. These cures operate because the infecting microbes have independent activities, or enzyme systems, which differ from those of the cells they infect; the drugs or antibiotics specifically interfere with these activities, and so, without seriously harming the person treated, prevent the microbes from multiplying.

But viruses have few or no independent synthetic systems. They seem to depend on the infected cells, not only for the substances from which they are made, as do parasitic microbes, but also for the systems by which they are made. Hence there is no obvious way in which they can be specifically checked from multiplying without also simultaneously interfering with the synthesis of the normal nucleoproteins which are necessary for the survival of the infected cell. Drugs and antibiotics are sometimes given to people with virus diseases; however, their purpose is not to cure the virus disease but only to prevent secondary complications that might arise from infections by bacteria or other microbes. The lack of curative treatments for virus diseases may, of course, be only a temporary phase in the development of pathology; but the prospect for success would be brighter if there were more evidence that viruses have some independent metabolic processes.

VACCINES

A cynic might thus be led to the gloomy conclusion that the brilliant successes achieved in controlling other kinds of infectious diseases are mainly ensuring a larger population in which viruses romp unchecked. But this would be very far from the truth. The fact that virus diseases cannot be cured, and that the prospects of curing them are not bright, does not mean that they have to be supinely endured. On the contrary, many of the important virus diseases of man are now controlled or controllable, and those about which little or nothing is done are mostly ailments that rarely kill or leave any lasting effects. For example, smallpox and yellow fever are no longer dreaded as they used to be, and although poliomyelitis still is, there is reason to hope it also will soon join the list of controllable virus diseases. With all these diseases, success depends on prevention, partly by the early diagnosis of infected individuals and their isolation from others, but mainly by treating individuals with specific vaccines that render them unlikely to contract infection even when exposed to it.

The idea of vaccinating people against virus diseases is far from novel. It was realized hundreds of years ago that a person who has once had smallpox and recovered, rarely contracts the disease a second time, even though exposed to it. This phenomenon is not peculiar to smallpox, but happens with many other virus diseases, one attack of which usually confers a lasting immunity on an individual. Since the pioneering work at the end of the eighteenth century by Jenner in protecting people against smallpox by giving them cow-pox (vaccinia), it has also been realized that the benefits of resistance may be acquired without the risks inseparable from infection with a virulent virus. The resistance develops because the presence of viruses stimulates an animal to produce specific kinds of proteins (antibodies), which circulate in its blood and combine with and inactivate virus particles.

Other kinds of germs (or, indeed, other kinds of protein too) also stimulate animals to produce antibodies; but antibodies produced by virus infections seem generally to last in the animal for longer than other kinds of antibodies. The aim of vaccines, then, is to behave like infections by bringing the antibody-forming mechanism into play, but to do so while having as little other effect as possible.

Two different kinds of vaccine are used successfully. One, usually called 'living' vaccine, is of the type introduced by Jenner; vaccination with these consists of actually infecting individuals, but doing so with harmless viruses that are related to harmful ones, that is, viruses which cause mild or no perceptible diseases although thay call forth antibodies that neutralize both the virus injected and related virulent ones. Thus, when human beings are infected with vaccinia virus they respond with only a localized lesion, but despite this the person is stimulated to produce antibodies that will react

both with vaccinia virus and with the related smallpox virus. Developing this kind of vaccine depends, of course, on discovering forms of virulent viruses that are harmless or nearly so, and reflects the potential variability of viruses. Some of the innocuous forms used as vaccines, like cow-pox virus, have been found occurring naturally, but others have been produced artificially by subjecting virulent viruses to unusual conditions in which innocuous forms have developed and then been selected. The first experimentally produced vaccine was made more than 60 years ago, before the existence of viruses as a special group of pathogens was recognized, when Pasteur showed that the virulence of rabies virus was decreased when it grew continuously in the central nervous system of a rabbit. By this method he derived the attenuated or 'fixed' virus from the virulent 'street' type.

The second type of vaccine ('killed') is generally not so satisfactory as the 'living' type, for it usually confers a less complete and a briefer protection. The person to be immunized is injected with the actual virus he is to be protected against, the virus having first been treated in some manner that prevents it from multiplying but does not destroy its ability to stimulate the production of antibodies. Although much more virus is normally injected than when a 'living' vaccine is used, fewer antibodies are formed, as the reaction against a 'living' vaccine is less to the virus that is inoculated into a person than to the virus that is produced when the infective virus multiplies. Usually more than one injection of an inactivated virus is needed to confer a useful resistance and, once the resistance has been built up, frequent injections may be needed to maintain it. Unless the virus injected has been freed from other proteins, the need to repeat the process may itself lead to complications; any proteins present in the vaccine are also likely to stimulate antibody production, and a second injection of a protein to which a person already possesses antibodies can cause troublesome allergies. The customary method of inactivating viruses when making vaccines is to treat them with formaldehyde. With many viruses this can be done without difficulty, because formaldehyde does not destroy their ability to stimulate antibodies unless it is many times more concentrated than is needed to destroy their infectivity. With others, however, the safety margin is much narrower, and conditions have to be strictly defined to ensure that the vaccine will not infect and yet will still produce antibodies.

Producing vaccines against viruses is more complicated than producing them against bacteria, for, as we have already seen, viruses cannot be grown in artificial media. Hence the first step towards getting a vaccine to protect human beings against a virus disease is to discover another animal, or some system of living cells, in which the virus can be propagated. Vaccinia virus, for instance, is usually multiplied on sheep, and several other vaccines are now produced by growing viruses in the developing embryos of fowls' eggs. The major achievement in producing a vaccine against poliomyelitis was

less the finding of a method for inactivating the virus than discovering a system in which the virus could be propagated in quantity. The virus is now propagated in monkeys' kidneys, a procedure so costly that it could only be contemplated for the control of a disease with such frightening potentialities. The fact that a vaccine has been prepared, however, is itself striking evidence of what can be achieved when research is sufficiently endowed, and it offers prospects of future successes against diseases that are now intractable. A 'killed' vaccine of this type is unlikely to be the last word in controlling poliomyelitis, not only because of the cost, but because, for the reasons already given, a 'living' vaccine of innocuous viruses would be preferable; there is no reason to suppose such vaccines will not be obtained if research on the problem is continued and intensified.

Poliomyelitis, like influenza, foot-and-mouth of cattle, and several others, is a disease that can be caused by more than one virus. This fact complicates vaccination, for it means that, to be fully effective, vaccines must contain viruses of all the different types. This fact, too, explains the difficulty in persuading people that virus infections are followed by a lasting immunity, because they remember only too vividly that they have had influenza more than once. But because they felt equally terrible each time, does not mean they were infected with the same virus each time: indeed, the odds are that they were not.

There is, then, the seemingly complex and paradoxical state of affairs that similar, or identical, diseases may be caused by viruses that produce quite different antibodies in the people they infect; whereas viruses that differ widely in virulence, so that one may be lethal and the other harmless, produce similar or identical antibodies. The second type is readily amenable to control by the use of 'living' vaccines, but the first is less easy to deal with by either type of vaccine.

Before leaving the subject of acquired resistance, a word should be said about the use of antibodies themselves. The kind of resistance we have been concerned with so far, in which individuals produce their own antibodies in direct response to a virus, is called 'active'; this is in contrast with the 'passive' resistance acquired when antibodies produced by some other organism are injected into an individual. This passive resistance has been widely used to protect people temporarily against the effects of infection by toxin-producing bacteria, such as those that cause diphtheria and tetanus.

No such success has attended attemps to control virus diseases by this method, although serum from the blood of people who have recovered from measles is sometimes given to lessen the effects of this disease in children. For a time there was some hope that children might be protected against poliomyelitis if they were injected with serum globulin (the fraction of blood that contains antibodies) from adults, most of whom have antibodies against these viruses, but a large-scale test in the U.S.A. showed no benefit from the

treatment. Where passive resistance does seem to be important is in conferring resistance to virus diseases on babies. Babies rarely contract virus diseases in the first few months of their lives, probably because their mothers have suffered from most of the common virus diseases and antibodies from the mother pass into the developing foetus.

VIRUS DISEASES OF PLANTS

If the past is any guide to the future, we can assume that an increasing number of the infectious diseases men now suffer from will become controllable, and that control measures will be increasingly applied the world over. This must extend the average length of life and thus increase populations still further, even though birth-rates may fall. Already the amount of food produced in some countries is not enough for existing populations to be adequately fed, and it would be a sad consequence of the triumphs of medical science if they led only to increasing numbers of hungry people. Fortunately, there are also great opportunities for increasing the production of food—provided the danger is appreciated in time and the problem tackled vigorously. Yields of many crops and animals over most of the world are miserably low and far below what could be produced by good farming. Good farming largely implies producing healthy crops and animals, by good feeding and the control of infectious diseases. The control of virus diseases provides only one of the ways to higher yield, but it is an important one, because viruses play a large part in determining current low yields.

There is no need to consider diseases of animals in any detail, because these raise much the same problems, and call for much the same control measures, as do virus diseases of man. One feature makes them simpler to control; as soon as animals are found to be infected, they can be killed and so stopped from acting as continuing sources of viruses for infecting other animals. In the United Kingdom, for example, even such an extremely infectious disease as foot-and-mouth of cattle is kept under control by a ruthless slaughter policy; the method may be unpleasant but, over the country as a whole, it probably costs less than would any vaccine however effective.

Destroying infected individuals, to safeguard the health of the others, is about the only feature common to the control of virus diseases in plants and animals. It is, too, one of the few recommendations that can be made generally for the control of all virus diseases of plants. In order to control serious virus diseases in men and animals, one can always aim at producing a vaccine that will confer resistance; and the less serious diseases raise little sense of urgency and can be left to run their course, for, although they may be temporarily unpleasant, sufferers will recover completely and then probably never contract the disease again.

Conditions are very different with virus diseases of plants; with these, there is no such obvious approach to a control measure, and it is vain to seek vaccines or to hope that crops will get over their troubles from viruses when they are young. This does not mean that viruses which infect plants differ fundamentally from those which infect animals; the big difference lies in the fact that plants have no mechanism comparable to that which makes antibodies in animals. When plant viruses are injected into animals, they stimulate antibodies, and the resulting antisera are very useful for identifying plant viruses, but even when viruses multiply and reach high concentrations in plants, the plants still fail to produce antibodies against them. Consequently, infected plants do not simply suffer a short illness, recover and then become immune. On the contrary, after rapidly invading all the vegetative parts (leaves, stems and roots) of plants, viruses remain active in these parts for as long as the parts remain alive. Some viruses quickly kill some kinds of plants, but more often they cause chronic, debilitating diseases, from which the infected plants continue to suffer for as long as they live; and still more important, when, as in common practice, vegetative parts of plants are used to produce new plants (as by tubers, bulbs, cuttings, runners, scions and the like), these new plants will also be infected.

Although viruses usually invade all the vegetative parts of plants, they rarely enter into true (sexually produced) seeds. Hence, with a few exceptions, annual crops raised from seed usually start their life virus-free; and although nearly all have their troubles from virus diseases, the losses are confined to one season and at least are not perpetuated; they can be regarded as losses of income rather than of capital. However, in perennial crops, or in crops that are propagated vegetatively—there are already very many, ranging from apples and bananas to potatoes and yams, and their number increases because this method of propagation can give uniform, high yielding crops—there is the equivalent of a capital loss, because infected stocks continue to be infected year after year. For as long as they are cultivated they supply sources of viruses for other plants. Also they can themselves become infected with other viruses, and the condition of some varieties that have been in cultivation for many years would be like that of a (fortunately mythical) human being, who would be simultaneously suffering from, say, mumps, measles, chicken pox and influenza.

This accumulation of viruses, which they never get rid of, causes varieties to yield less and less as they grow old, a phenomenon often described as 'degeneration', 'senility' or 'running-out' of a stock and wrongly attributed to a deleterious effect inseparable from vegetative propagation. The fact that more vigorous offspring are obtained when true seed is sown from such plants than when offspring are produced from them by vegetative propagation is not due—as was widely believed—to any intrinsic invigorating effect of sexual reproduction, but to the elimination of the debilitating viruses that

were infecting the parents. Many a virus can by itself cause serious disease, but as often as not the increasing loss of cropping power in perennial or vegetatively propagated crops is due to infections by an increasing number of viruses. The combined effect of two viruses is sometimes simply the sum of the two effects, but often it amounts to much more than the simple sum; viruses which separately do little harm, together are often crippling, a phenomenon that would be paralleled in human beings if simultaneous infection with, say, the common cold and chicken pox could produce the symptoms of paralytic poliomyelitis.

The varieties of many plants now in cultivation are in this kind of condition, and it is small wonder they yield so poorly; the replacement of these virus-ridden stocks with healthy ones could increase productivity immensely. One example will suffice to illustrate what can be done in this respect: new virus-free varieties of cassava in East Africa yielded seven times as much as the ones in general cultivation there.

The control of virus diseases of plants, as of animals, lies in prevention, for although plants can be cured of a few virus diseases, the necessary treatments are rarely applicable on a large scale; they usually serve only to provide an initial virus-free stock, which can then be multiplied to make commercial quantities. The need to ensure healthy planting material is becoming more widely recognized, and some countries already operate schemes for supplying growers with virus-free stocks of potatoes and other vegetatively propagated plants. It is no coincidence that yields of these crops are highest in the countries which operate such schemes. But virus-free stocks will not remain virus-free indefinitely; they will need either protection or replacement with new ones at intervals. So far, replacing has been the usual method. There are hopes, however, that protection will become increasingly possible, particularly if the many sources of plant viruses that now abound are sought out and rigorously destroyed.

SPREAD BY INSECTS

No other general recommendation can be given, for each disease raises its own problems, and the best ways of dealing with it can only be decided by discovering the sources of the viruses and the way in which they spread. When it comes to seeking the method whereby a plant virus spreads, all past work shows that it is reasonable first to suspect some insect. Some animal viruses, such as yellow fever and myxomatosis, are also insect-transmitted; but many are airborne, and for this there is no counterpart in plant viruses. Transmission of a virus by insects is usually a specific process, and not something that any insect can do. Sometimes the search for the insect responsible is made relatively easy by the fact that it is also a common pest

of the affected crop, but this is not always the case. Viruses are often spread extensively in crops by insects that are never abundant enough to constitute pests of the crop; the search then may be protracted, particularly as species that may transmit the virus occur among many diverse groups. Most of these are insects that feed by sucking juice from plants; the most important are aphids, leaf-hoppers, mealy-bugs, white-fly and thrips, but the biting insects, such as beetles and grass-hoppers, cannot be wholly neglected, for they do transmit some viruses.

The details of the processes whereby insects transmit plant viruses are incompletely known, and the specific ability of insects to transmit individual viruses are unexplained; but different viruses and vectors behave in very different ways. At one extreme are some of the viruses transmitted by aphids: aphids can acquire these viruses by feeding on an infected plant for less than a minute, and within another minute can infect a healthy plant. It is a fortunate compensation that the viruses that are so rapidly acquired are also almost equally rapidly lost by the insects.

At the other extreme are some of the viruses transmitted by leaf-hoppers, which may have to feed for hours on an infected plant before they pick up the virus, and then usually have to wait a further period of days before they can transmit it to healthy plants. To compensate for their dilatoriness in becoming infective, however, these insects remain able to infect healthy plants for long periods, often for the remainder of their lives. Some viruses in this category multiply in the insects that transmit them, and it is uncertain whether they should be regarded as animal or plant viruses. As some seem to multiply rather more readily in their insect than in their plant hosts, and are so well adapted to the insect that they can pass from one generation to another through the insect's eggs, they may well be primarily insect viruses. However, it is in plants that they are important, for these they cripple, whereas they seem not to harm the insects they infect.

Between the two extremes—of viruses that are rapidly acquired and rapidly lost by insects, and viruses that are acquired slowly but maintained for long periods—are viruses that show various intermediate types of behaviour. Without going into details, it may be pointed out here that this type of information is not merely of academic interest but has practical importance in deciding what kind of control measure is likely to succeed.

Many of the insects that transmit plant viruses are also pests which directly damage crops by their feeding. There is now a range of insecticides that deal with insect pests, and it is therefore reasonable to inquire why virus diseases are still troublesome. At first sight, their control would seem to raise no great problems; it surely should follow automatically when the insect vectors are killed. However, even if all the world's crops were sprayed against pests—and at present only a very small proportion is—virus diseases would still spread.

Unfortunately the control of the insect vector of a virus disease is a different problem from, and more difficult than, the control of the same insect as a pest. To prevent an insect from doing direct damage demands only that its numbers be kept small, but the rate at which virus diseases increase is not determined simply by the number of vector insects that are produced in a crop. If an insect is to transmit a virus, it must move, whereas direct damage by feeding is done mostly by stationary insects. Movement is more important than numbers in spreading viruses. The greater mobility of leaf-hoppers, for example, makes them generally more effective vectors of viruses than are aphids; and most of the enormous numbers of aphids that often infest plants are wingless, and these do little transmitting of viruses compared with the relatively few winged ones. The control problem, then, is to deal with the moving insects.

Although most potato virus diseases are spread by aphids, spraying potato crops with insecticides that kill aphids has often increased rather than decreased the spread of virus diseases. This paradoxical result has two explanations. First, if wingless aphids are not killed quickly, some that would have remained stationary are affected by the spray and move to nearby plants, which they then infect. Secondly, the life of potato crops is often considerably prolonged by spraying with insecticides like DDT, and, when the unsprayed crops die, the winged aphids migrate from them to the still green, sprayed, crops and take with them their viruses.

However, in some circumstances spraying with an insecticide greatly decreases the spread of virus diseases. The number of virus-infected plants in a crop increases in two ways: by the infection of plants by insects which are already infective when they come into the crop; by spread through insects from infected to healthy plants within the crop. There is little evidence yet that spraying a crop will do much to prevent the first, but some of the newer insecticides do check the second; and they are particularly effective against viruses whose vectors do not immediately become able to transmit after they have fed on an infected plant.

Knowledge on plant viruses and virus diseases has increased rapidly in recent years, but even so we are at the stage of beginning to appreciate the many complex problems they set rather than at the stage of finding solutions for them. What can be achieved is shown by the fact that, within less than 20 years, the United Kingdom has been virtually freed from the serious virus diseases that used to be so common in potato crops. There is no reason to think that the same thing could not be done elsewhere, if only the same effort were made. Again, in parts of the U.S.A., where sugar-beet growing had to be abandoned some years ago because of virus diseases, it is now again a flourishing crop because resistant varieties have been bred; and, for the same reason, the justifiable fear once held, that mosaic disease would make sugar-cane growing impossible, has now been dissipated.

Nevertheless, virus diseases still go unchecked in most of the world's crops, either because control measures have not been discovered or because they are not applied. Finding and applying these measures will not be simple, but the effort must be made if the increasing population is not to go hungry. The first step must be to realize the great importance of the health of crops, and to be prepared to spend much more money than in the past on botanical research. And it must be spent specifically for this purpose and not, as sometimes happens now, because it is hoped that results obtained with plant viruses may help to control poliomyelitis or cancer. It is understandable that man should put his own ailments first, but we are now threatened with the absurd possibility of a vast human population, freed from infectious diseases and equipped with all the apparatus of modern technology to enjoy their leisure, faced with a real danger of going hungry. It is quite time to recognize that almost everything else is secondary to ensuring enough food.

CANCER AND BACTERIAL VIRUSES

As cancer is considered by some people to be a virus disease, a few words should be said about what is probably the most dreaded human disease. That some tumours, in both animals and plants, have transmissible causes has been established beyond doubt, but there is no such evidence for human cancer. Not only is cancer obviously not infectious as is, say, influenza, but in some individuals it seems to spread from cell to cell for no cause, and cancerous cells occur close to normal ones. Thus, as a non-infectious disease, cancer cannot come under our definition of virus diseases.

Nevertheless, there are many analogies between cancerous and virus-infected cells. They are both endowed with growth and metabolic capabilities different from normal cells, and the abnormal growth of cancer cells can sometimes be simulated by virus infections. The main distinction is that cancerous cells seem to owe their peculiar qualities not to something coming from another cell, but rather to intrinsic changes in the cancerous cells, changes usually produced as a response to some stimulus, often a specific chemical. These stimuli may act by changing the genetic determinants and so confer new metabolic activities on the cells. We have already seen that, in their chemical constitution, viruses closely resemble normal components, the chromosomes and plasmagenes, which determine the specific activities of cells. The differences lie mainly in the fact that viruses can spread from one cell to another, whereas plasmagenes do not appear to do so. The differences are slighter than the similarities; indeed they may well be largely a matter of semantics: when transmissibility is established the unit is usually called a virus, and when it is not established the unit is called a plasmagene.

With bacteria the border-line between infection and heredity is becoming increasingly vague, and transmissible units that affect the behaviour of but do not kill bacteria are regarded as genetic characters and not as viruses. It seems, too, from recent work, that what were for long considered to be unequivocal viruses can occur in cells in two different states, one as a lethal virus that dissolves the cells, and the other as a seemingly harmless unit that is inherited by daughter cells. Perpetuated in the second state the virus behaves like a part of the normal genetic mechanism of the cell, and such bacteria do not seem to contain any particles with the characteristic shapes of the lethal virus. Occasional cells, however, spontaneously produce the lethal virus particles and are killed. This potentiality to produce virus particles can be changed to an actuality by giving a culture an appropriate stimulus, of which many are known. Then all the cells in a culture will produce virus particles and the whole culture will be destroyed.

Have these processes any relevance to cancer? Is the first an analogy for the spontaneous cancers? Or the second for the cancers produced when skin cells and lung cells are given appropriate stimuli? Do all cells carry in their own genetic constitution the potentialities of becoming cancerous when exposed to an appropriate stimulus? Or do they first have to contract some extrinsic particle that stays latent and harmless until the cell gets the correct stimulus?

None of these questions is now answerable, but the road to getting answers seems open, and whether cancer ultimately is classified as a virus disease or not, there is little doubt that the problems it sets are likely to be illuminated by research on viruses.

The Peaceful Uses of Atomic Energy

ENERGY PRODUCTION AT THE GENEVA CONFERENCE (8-20 August 1955)

by

P. TARANGER

This article, following on that published in the last number of Impact,[1] *sums up the possibilities of using atomic energy as a source of mechanical and electrical power, as described in the papers submitted at the Conference on the Peaceful Uses of Atomic Energy, held in Geneva from 8 to 20 August 1955. The author, who worked for 15 years in the petroleum industry in France and abroad, is at present Industrial Director at the French Atomic Energy Commission and, as such, in charge of the application of atomic energy to French industry.*

INTRODUCTION

In 1942, world consumption of petroleum products exceeded, for the first time, the new supplies discovered during the year. Such a situation does not seem to have recurred since; but when the fact was published at the end of the war, it aroused some apprehension. For how much longer would we be able to meet the ever-increasing demand for energy?

This anxiety led to a large number of studies designed to forecast future energy supplies in the light of the past and present situation. Most countries now possess ample data relating to the consumption of energy of all kinds, its previous evolution, and even future requirements. Certain general ideas, and also some striking pictures, are revealed by studies—such as the idea of 'mechanical slaves', or the automatic way of relating a country's standard of living to the average consumption of energy per head of population.

Just when everything was about to fall into place, and a policy was about to be adopted to facilitate decisions regarding equipment, a new source of energy appeared: the splitting of the atom gave rise to atomic energy. It was surrounded at first by an atmosphere of secrecy, inevitably bound up with its originally purely military applications; and this helped to make it appear frightening and mysterious.

1. 'Biology and Medicine at the Geneva Conference (8-20 August 1955)', by Jean Coursaget, *Impact*, Vol. VII, No. 1, March 1956, pp. 34-61.

Some people thought that it was very difficult, and in any case dangerous, to produce nuclear electricity, and that this would not be done for several generations. Others, on the contrary, were convinced that within a very few years new plants would produce an unlimited quantity of energy, at hardly any cost at all. Others, again, thought that *in medio stat virtus*. But all were eager to know more.

In this respect, the Geneva Conference had the great merit of bringing together many national points of view, and to some extent lifting the veil which had covered recent achievements in nuclear physics and technology. For two weeks, the delegates of 84 countries of East and West exchanged information and communicated to each other certain of the results of their experiments. They spoke of their hopes and described their difficulties—and this for the first time in an atmosphere in which, if secrecy was not altogether absent, at least the great Powers vied with one another in reducing their 'classified' data.

Those who were privileged to follow this remarkable procedure from start to finish obtained from it, not merely a fund of knowledge, but above all a clearer idea of what is and what is not yet possible, of what is known for certain and what remains to be demonstrated, of what is generally accepted and what is still disputed. They heard the opinions of the greatest world specialists, and came away with more accurate views about the way in which atomic energy is likely to combine with traditional sources of energy in the years to come.

THE BALANCE SHEET OF CONVENTIONAL ENERGY

In order to determine the importance of atomic energy in relation to traditional sources of power, we must first of all consider the extent to which the latter have been able to meet man's requirements in the past and will be able to meet them in the future. Numerous papers were contributed on this subject, and from these a number of general ideas emerged which it may be useful to summarize.

A study of the past, and the forecasts for the immediate future, reveal—in accordance with laws which seem to defy frontiers—a demand for power supplies which is yearly increasing at a fairly constant rate. Naturally, the percentage of increase differs according to the nature of the energy considered; but these differences are tending to lessen. Thus, the consumption of gross energy does not increase at the same rate as that of effective energy. Efficiency is increasing, since in the world as a whole it has risen from 11 per cent to 22 per cent between 1900 and 1950 (paper A/CONF.8/P/1116 from the Department of Economic and Social Affairs of the United Nations). However, efficiency has its limits, and the evolution of the consumption of

gross energy will tend more and more to coincide with that of effective energy.

In the same way, a general increase in energy requirements can be seen; according to the country and the author, it varies on the average between 2 per cent and 4 per cent per annum. On the other hand, electricity consumption is increasing at the rate of 6-7 per cent a year, which means that it doubles every 10 years. It is clear, therefore, that electricity's share in the total sum of energy is increasing and, as a result, the disparity between the rate of increase in gross energy and that in effective energy will tend to decrease.

Most authors, anxious not to indulge in prophecy and risk contradiction by facts, emphasize that prediction becomes more difficult the further one looks into the future. Thus, P. Ailleret (A/CONF.8/P/326) gives no forecasts for the period after 1975. E. A. G. Robinson and G. H. Daniel (A/CONF.8/P/757) write: 'Accurate prediction of the power requirements for the years 1975-2000 is an impossibility'.

Nothing, however, authorizes us to think that the present trends will not continue beyond 1975, for example; and this seems to be confirmed by a study of consumption in the most highly industrialized countries.

A very complete inventory of the reserves of classical sources of energy (water power, coal, petroleum, gas, etc.) was presented at the Conference. The study of it, country by country, is a forbidding task; its chief effect is to reveal clearly the uneven geographical distribution of energy resources in relation to needs. The paper mentioned above (A/CONF.8/P/1116), however, provides an instructive synthesis, since it enables us to form a more complete idea of the question than that contained in the notion of supplies alone; it refers to maximum annual possibilities of extraction—as related to price, of course—which in each case not only determine the actual life of reserves, but also place a ceiling on a possible increase in the production of energy from any given source.

The comparison of requirements with reserves, on a world scale, shows a fairly encouraging situation: world power reserves are sufficient to meet relentlessly increasing needs for more than a century to come. But the position changes as soon as frontiers—or prices— are considered: the uneven geographical distribution of sources of supply in relation to areas of consumption brings to light at once the crucial part played by transport as a limiting factor. Thus, very few regions of the world can have any assurance of being able to meet their power requirements up to the year 2000 without a considerable increase in prices. Indeed, if they had access to conventional sources of power alone, most countries would sooner or later—and in some cases very soon—have to pay more for their power, thus limiting their potentialities for progress.

To what extent, then, can nuclear energy provide a solution for the problem as stated in these terms?

ATOMIC SOLUTION: THE CONDITIONS

The solution for this probable shortage of power—and especially power in its most refined form, i.e. mechanical or electrical power—depends on the answer to the three following questions.

The first is a statistical one: is nuclear fuel (uranium and thorium) obtainable in large quantities?

The second is technical: is it possible to produce electricity by splitting the atoms of the heavy elements which constitute nuclear fuel? And if so, how?

The third, a purely economic question, repeats the first two from the standpoint of cost price: what will nuclear electricity cost?

In actual fact, we had certain data which provided part of the answer to these questions, even before the Geneva Conference. The approximate uranium output of certain countries was already known; and press reports, together with the prices charged by factories treating uranium, etc., already gave us some idea of the situation.

It was also known that electricity had already been produced: a 150 kW plant was set up for the first time in 1951 at Arco (Idaho), and another 150 kW plant in 1952 at Oakridge (Tennessee). We knew of the existence of the submarine *Nautilus*—whose engine is in fact a small generating plant —and of a 5,000 kW power plant in the Union of Soviet Socialist Republics. The principle of these experiments was known, as well as the principles underlying an American five-year plan for five simultaneous experiments, also those of the British 10-year plan made public early in 1955. Generally speaking, however, we had no details of how the experiments were to be carried out: how could anyone have foreseen the part to be played by aviation in transport merely on hearing a statement of the principle governing bodies heavier than air, even had it been accompanied by a photograph of Blériot's first aeroplane?

Lastly, the economic aspect of the situation had been touched upon in numerous publications; but their often unscientific and even tendentious character, the authors' reluctance to reveal the facts on which they based their estimates, and the absence of any direct contact with those authors—which would have made it easier to know what facts they took for granted and what they were seeking to prove—made such information far too undependable.

At Geneva, on the other hand, many facts were revealed. Objective but animated discussions, arising out of papers full of information, enabled answers to be supplied to the three questions. These answers are doubtless still incomplete, and only experience can eliminate the uncertainties which still remain; but they take into account practically all the known facts. It is these facts which are outlined below.

URANIUM SUPPLIES

The information on uranium reserves accumulated by each country during the past ten years has been jealously guarded as a military secret.

At first sight, it would seem that the Geneva Conference, in emphasizing the peaceful applications of atomic energy, should have broken down these barriers. However, only the United States of America presented a paper giving statistical information (A/CONF.8/P/470, by Jesse C. Johnson). It is true that the author, who is Director of the Division of Raw Materials of the U.S. Atomic Energy Commission, is in possession of information ranging far beyond his own country; his paper thus has such a wide scope that only the information relating to the countries of the East is missing from the picture.

Reading this paper those who know something of oil prospecting cannot fail to draw a parallel between the search for oil and the search for uranium. They know that oil is generally present where it is looked for, and not merely where it has been discovered. It was well known, some years ago, that the Belgian Congo and Canada possessed rich uranium deposits. Those searching for it elsewhere have since found it—in the United States of America, in South Africa, Australia, France and Portugal.

The evaluation of reserves depends, of course, on the price one is prepared to pay for the finished product. If increasingly poor ores are worked, the reserves, of course become greater. Thus, at the price at which the richest ore is at present worked—about \$28 or £10 per kilogramme of uranium contained in the concentrated oxide U_3O_8—there are almost 2 million tons of reserves. Some millions of tons could be added to this figure by accepting a price ranging from \$28 to \$85 (£10 to £30), and the figure of 20 million tons could be reached if the price were raised to about \$143 (£50) per kilogramme. Moreover, methods of prospecting and of processing the ores are continually being improved, so that it is not unreasonable to consider these prices—which are calculated on the basis of present techniques—as maxima.

Theoretically, the energy contained in a ton of uranium is roughly equal to that contained in 3 million tons of coal. Consequently, according to whether the oxide costs \$28 or \$143 per kilogramme (£10 or £50), uranium reserves represent—still theoretically—from two to twenty times the reserves of coal (at a theoretical price from 1,000 to 200 times less than the coal calorie).

These are theoretical considerations which will be developed later, in connexion with the yield to be expected from nuclear fuels. Here we will merely mention that a 5 per cent yield makes nuclear fuels as plentiful as coal, and at a relatively low cost. In fact, a 1 per cent yield has already been achieved, and it is hoped to reach a yield of 30 per cent.

TECHNICAL ASPECTS OF REACTORS

In his paper A/CONF.8/P/862, Alvin M. Weinberg estimates at 900 the number of types of reactor that can be imagined by combining all kinds of fissile materials, breeder materials, coolants and moderators, according to the geometrical structure or energy levels of the neutrons. Common sense reduces to 100 the number whose construction is not impracticable, and Weinberg estimates at a dozen those which have a good chance of functioning correctly.

This is approximately the number of machines described at Geneva, the same type having frequently been studied independently by technicians of different countries. It was interesting to discover that, notwithstanding national frontiers, 'schools' are beginning to grow up, and that those planning or constructing reactors believe that their own particular type has the most chance of success. This observation, made verbally by A. M. Weinberg during the often very animated discussions arising out of the papers, emphasizes not only the passionate enthusiasm of the research teams, but the faith they have in their own work.

We shall confine ourselves here to listing the main types of reactor and pointing out their essential features. The technical details will be found in the papers themselves, for which references are given below.

Graphite Moderated Reactor

Although this is not one of the most 'advanced' types, it should be mentioned first, because it provides a good example of similar developments occurring in different countries and leading to similar solutions.

The papers A/CONF.8/P/406 by Sir Christopher Hinton and A/CONF. 8/P/337 by Pierre Ailleret and P. Taranger describe, in fact, the reactors of this type under construction at Calder Hall in England and at Marcoule in France. The similar line of thought followed on each side of the Channel is still more striking if we recall that on both sides these constructions, in which the coolant is compressed carbon dioxide gas, were preceded by similar constructions cooled with atmospheric air.

However, it does not occur to anyone that the Unied Kingdom might have copied France, since generally speaking it is more advanced than France in the field of atomic energy; nor indeed that France might have copied England, since it was the French who first introduced the use of compressed gas (A/CONF.8/P/387 by J. Yvon, on the Saclay reactor).

It is of interest to note that these independent studies may lead to different solutions for certain identical difficulties, and this is a factor which makes for progress.

Pressurized Water Reactors

These use enriched uranium as fuel, and ordinary water as a moderator and coolant. The American 60 megawatt generating station under construction at Shippingport, Pennsylvania (A/CONF.8/P/815), and the Russian 5 megawatt plant already operating in Moscow (A/CONF.8/P/615, by D. V. Blokhintsev and N. A. Nikolayev) are both working on this principle, though with certain minor differences. The former is derived from the engine of the submarine *Nautilus*; the second uses perhaps a more enriched type of uranium, but has recourse to stainless steel rather than to zirconium, which, the authors state, will not be the case in larger projects aiming at greater economy.

Sodium Graphite Reactor

This model is being developed in the United States (A/CONF.8/P/493, by Chauncey Starr). It uses graphite as a moderator, liquid sodium as a coolant and, as fuel, either slightly enriched uranium or a highly-enriched mixed charge of thorium and uranium.

This project is still in course of realization; like the preceding type, it represents one of the five main ways in which the United States of America is facing the problem.

Boiling Water Reactor

Water boiling in the reactor itself distinguishes this new type from those in which a secondary circuit avoids contamination of the turbine; one circuit can thus be eliminated. Several American or Russian variants were described at Geneva, water being in each case the moderator and the heat transfer medium. Fuel may be either in the form of solid elements, or else dissolved in water. Either heavy water or ordinary water may be used. (A/CONF. 8/P/497, by J. M. Harrer; A/CONF.8/P/851, by W. H. Zinn; and A/CONF.8/P/624, by A. I. Alichanov.)

Breeder Reactors

Breeder reactors, which, as will be seen later, seem to be the most promising type, were presented in two distinct categories:

1. The homogeneous power reactor, where the fuel is dissolved in the moderator (water) and which consequently works with thermal neutrons. In this case the fuel is uranium 235 (later uranium 233). The 'blanket' where the fuel is reproduced, is an aqueous solution of a thorium salt. (A/CONF.8/P/496, by R. B. Briggs and J. A. Swartout; A/CONF. 8/P/498, by S. E. Beall and J.A. Swartout.)

2. The fast breeder reactor works, on the contrary, with fast neutrons, and therefore without a moderator. The coolant is a molten metal (sodium), the fuel is uranium 235 (later plutonium 239), and the 'blanket' natural uranium. This model has been studied and is being constructed in England (A/CONF.8/P/405, by J. W. Kendall and T. M. Fry) and the United States of America (A/CONF.8/P/501) simultaneously.

This list perhaps neglects certain promising types, although it is probable that a more thorough study of such types would make their prospects of success less certain. It must however be emphasized that the existence of all these types of reactor, their very number contains in itself—by the many possibilities it opens up—a fair promise of success.

ECONOMIC ASPECTS

Certain of the authors whose papers have here been mentioned put forward estimates of costs per kilowatt-hour produced. For example, C. Starr (A/CONF.8/P/493) expects from the 'sodium graphite' generators a price of between 6 and 8 thousandths of a dollar (0.5-0.7d.) per kilowatt-hour. Similarly (A/CONF.8/P/501 already quoted) it is thought that a 'fast' breeder reactor using plutonium will be able to produce electricity at a price of between 8.09 and 8.77 thousandths of a dollar (0.7-0.75d.) per kilowatt-hour, according to the value attributed to the surplus plutonium produced. But a more general study would be necessary in order to give an accurate idea of what can be expected in the near or more distant future.

The machines that will be used will be very similar to basic thermal power plants, with the furnaces replaced by reactors. Thus their economic aspects should be studied in the same way as those of thermal power plants, i.e. by considering in turn the necessary investments and the operating costs, or at least the most important of the latter—the cost of fuel.

Investments

The papers presented on various types of nuclear power stations generally mentioned the cost per kilowatt of capacity. At least, the American studies, which were the most advanced, did so. The figures indicated are between \$150 and \$500 (£53.10 and £178). This difference reflects not only the considerable variations in the size of the installations (ranging from 9,000 to more than 1,000,000 kilowatts), but also the different stages reached in research, and even in some cases the influence of the author's temperament.

The paper A/CONF.8/P/477, presented by W. Kenneth Davis, analyses the various aspects of the problem. The standing of the author—a former oil engineer, and at present Director of the Division of Reactor Development of

the U.S. Atomic Energy Commission—lends particular weight to his opinion.

Davis considers that the most accurate figures are to be derived from the projects which are the most advanced industrially, and he gives them as between $235 and $250 (£84 and £89) per kilowatt of capacity. This, of course, refers to plants under construction or on the point of being constructed, whereas those to be constructed in the near future should cost from 10 to 20 per cent less. 'It should be noted', he says, 'that the scientists and engineers who have studied the problem have concluded that there is no reason why nuclear power plants, at least of appreciable size, cannot be constructed as cheaply as conventional power plants, if not more cheaply. We still have a long way to go to achieve this goal—perhaps five or ten years—but we are making good progress.'

The author goes beyond the matter of power plants, and assesses all the investments required for the whole nuclear electricity chain, ranging from the uranium mine, through the chemical and metallurgical factories, etc., to the evacuation of waste. In this way he arrives at a total figure of $350 (£125) per kilowatt, which he compares with the $310 (£111) of the coal-producing chain from the mine to the power plant, including $135 (£48) for the latter. Once again, these figures are based on current projects, and should decrease with the next 'generation' of nuclear power plants, dropping to $250 (£89) in five or ten years' time.

Here a personal opinion may perhaps be allowed. At Geneva, we were somewhat surprised at the moderate nature of these estimates. But subsequent conversations with the author have cleared up many points. In the first place, it is important to break away from the traditional attitude of the Old World, and to envisage plants of considerable size, with consequent low costs for fuel, materials and machines.

It must also be borne in mind that W. K. Davis has calculated costs for an *established* industry—which is not yet the case with nuclear energy—and not for an experimental plant, in which, for instance, no suitable provision has been made for paying off research costs. Incidentally, these are considerations that must be taken into account when deciding whether a certain new machine can compete with another which is already being mass-produced.

Apart from considering investment as related to kilowatt capacity, account must also be taken of the time the plant will last—a factor which also influences the cost of the kilowatt-hour. It is important that machines should not wear out too quickly, if investments are to be paid off satisfactorily. Naturally, the time needed for this amortization depends, according to country or period, on the price of money.

In the papers presented at Geneva there are few indications of this kind —except in one case, where the figure of twenty years is put forward (A/CONF.8/P/493). This seems reasonable, since some atomic reactors

have already lasted about ten years. Any anxiety that these machines might be too short-lived is allayed by the growing knowledge of the special materials required and of their behaviour, and also by the fact that the reactor is merely one part of the whole power plant—the other sections (engineering construction, turbo-alternators, transformers, etc.) being of the classic type.

Proportional Costs: Fuel

If investments constitute almost the whole of the permanent costs of a nuclear power plant, fuel represents the main part of the operating costs, which are proportional to the number of kilowatt-hours produced.

Strictly speaking, we should investigate thoroughly such items as operational and maintenance costs, in order to compare them with those of power stations of the conventional type. But they are in any event very small, and comparable to those of present-day power stations; this, at any rate, seems clear from the studies presented at Geneva. The staff required, for instance, is much the same in both cases.

It seems much more to the point to make a thorough study of the fuel question in general, which is rather complicated but of basic importance for the future of this new source of energy.

It should be recalled that there are two sources of nuclear fuel: natural uranium and thorium. Natural uranium is a mixture, in fixed proportions, of one part of the uranium isotope 235 to 139 parts of the isotope 238. Uranium 235 undergoes fission in the reactors (it is known as fissile material) and is a nuclear fuel, *the only one to be found in nature.*

But uranium 238 possesses the remarkable property of absorbing the neutrons in a reactor where fission is taking place, and of converting itself into plutonium 239, also a fissile material and therefore a new artificial nuclear fuel. This is why uranium 238 is known as a breeder material. Thorium 232 is also a breeder material; under similar conditions, it gives rise to uranium 233, a fissile material, and therefore a third nuclear fuel. Thus, we know of two breeder materials—uranium 238 and thorium 232, and three fuels—uranium 235, plutonium 239 and uranium 233.

Some remarks are called for on this point. Since uranium 235 is the only natural nuclear fuel, it must be the starting point for all atomic industry. Two ways lie open. The simplest is to make natural-uranium reactors; the other is to separate the two isotopes 235 and 238 and thus obtain either a pure or an enriched fuel. It is well known that this separation, a very difficult process, is carried out in very costly plants (costing as much as a thousand million dollars, for example) with a high power consumption (thousands of millions of kilowatt-hours per year in the United States of America). And so, though all countries have begun or are beginning to

build up their atomic industry on natural-uranium reactors, only the United States of America, the Union of Soviet Socialist Republics, and the United Kingdom have, so far, also built separation plants.

The association, in a reactor, of a breeder material with a fuel makes it possible to combine the consumption of the latter with the production of a new fuel. The relation of the weight of the new fuel thus produced to the weight of fuel consumed is known as the *conversion rate*. It is clear that 'breeders' for which this ratio exceeds one have an all-important bearing on the economy of atomic energy production.

It must also be borne in mind that uranium 235 is practically non-poisonous—unlike uranium 233 and, especially, unlike plutonium. Moreover, the properties (e.g. mechanical or metallurgical) of uranium 235 and 233 are identical with those of natural uranium, and therefore much better known than those of plutonium, which was discovered later. As a result, the availability of uranium 235 (from the separation plants) tends to postpone the use of plutonium.

The fissile or breeder materials in a reactor must be chemically processed as soon as they are 'contaminated' by the products of the fission, or whenever it is desired to extract the new fuel produced. This processing, which involves the destruction and then the reconditioning of the charges, must be carried out periodically, and is most expensive. It involves radiation chemistry, necessitating the use of shields and remote controls—in a word, it demands very costly equipment.

Of the types of reactors listed above, three main classes of machines have attracted special attention:

1. Those using natural uranium (with a conversion rate of slightly under 1).
2. Those consuming enriched uranium (with a conversion rate which is usually well under 1).
3. 'Breeders' working on the uranium-plutonium cycle or on the thorium-uranium 233 cycle (with a conversion rate exceeding 1) and which may, when required, be set in operation, in each case, with uranium 235.

Unless there is an isotope separation unit available, natural-uranium reactors —known as primary reactors—are the necessary starting-point for the production of plutonium, and therefore for obtaining breeders. As a result, one must expect to see many power plants of this kind springing up—in England and France, for example. The cost per kilowatt-hour includes a proportion for the fuel, which results from the yield with which the natural uranium is utilized. A single charge is expected to produce a heat of at least 3,000 megawatt-days per ton (or 72,000 kilowatt-hours per kilogramme), i.e. about 10,000 times more heat than is produced by the same weight of coal (A/CONF.8/P/389, by Sir John Cockroft). If one accepts the prices indicated above for uranium extracted from fairly rich ores (about $28 or £10 per kilogramme), adding to it an equivalent sum for operations such

as converting the technical uranium salt into pure metal conditioned for the reactor, it is seen that, for the simplest type of machine contemplated, nuclear fuel is cheaper than coal.

Sir John Cockroft, recalling another British contribution (A/CONF. 8/P/403, by J. V. Dunworth), contemplates the re-utilization, after chemical processing, of the first charge, in which the plutonium produced replaces the uranium consumed. He thinks that in this event it will be possible to obtain an output ten times greater, i.e. to extract 720,000 kilowatt-hours of heat from each kilogramme of uranium. This would lead to a new drop in the price of fuel as soon as chemical treatments made this method possible.

The enriched-uranium reactors, when this precious product is available, are easier to construct than the previous types. They require a plant of relatively moderate size, thus allowing successive experiments to be carried out more cheaply, and the utilization of more advantageous constituent materials, because of a more favourable neutron balance-sheet. But it seems necessary, except for experimental purposes, to prohibit the use of this enriched fuel, unless it is combined with breeder material suitably placed, since too low a conversion rate would be uneconomical (A/CONF.8/P/403, quoted above).

With this reservation, it seems that the use of enriched uranium should lead to fuel prices slightly lower than those obtained with natural uranium, at least in cases where isotope separation plants allow of relatively low costs. As no indications were given at Geneva on the composition of these prices, and their variations in relation to the enrichment rate, we can only express a personal opinion—supported, it is true, by the American experts' descriptions of the types of machines they are constructing.

Enriched-uranium reactors, like natural-uranium reactors, use as fuel uranium 235, of which natural uranium contains only one part in 140. They therefore limit considerably the potential output of the nuclear electricity industry. Sir John Cockroft had already emphasized that the re-utilization of impoverished uranium, mixed with plutonium, is a possibility which increases production tenfold. He also indicates a way of increasing it tenfold again, and managing to extract a quantity of heat exceeding 7 million kilowatt-hours from every kilogramme of uranium.

This is done by using the breeder reactor, working, for example, on the uranium-plutonium cycle. The core of the reactor is filled with a given quantity of plutonium. While it is functioning and producing electricity, uranium, arranged in a 'blanket' around the core, reproduces a quantity of plutonium in excess of that being consumed in the core. Periodically, a chemical treatment enables this new plutonium to be extracted, that which has been consumed in the core to be replaced, and stocks to be built up for setting other machines in motion.

It is clear that an output of this kind makes completely negligible the influence of the original cost of uranium on the cost of the energy produced. The chief expenditure is that involved in the chemical processing. This is costly, but progress is being made, and already it is certain that the proportional costs attributable to it will be five or ten times less than the cost of coal in a thermal power station.

It is therefore not surprising if the best qualified American, British and Russian authors believe that the breeder reactor holds out the most promise for the future. So far, however, it is only a promise, for these machines are very difficult to construct and raise major technological problems. All experts predict that a good ten years will be required for these problems to be solved.

THE INTEGRATION OF ATOMIC POWER INTO ENERGY RESOURCES

Three basic facts seem to emerge from the lessons learned at Geneva:

1. Nuclear fuels are abundant and can be obtained at reasonable prices.
2. Several types of machine, constantly being perfected, can produce energy, extracting from these nuclear fuels a continually increasing output.
3. The cost of this energy, at present a little greater than that of energy obtained from coal or petroleum, will fall to about the same level in a few years' time, and will be lower than that from coal or oil in ten or twenty years' time.

This latter conclusion arises out of the observation that investments, which are at present greater than those required by a conventional power station, will gradually diminish to reach approximately the same level, and that fuel costs, which are at present a little less than those of conventional power stations, will be much less in ten years' time.

Uranium can therefore already be considered as a supplementary source of primary power, to be integrated—in the ways indicated below—into the present sources from which mankind obtains the energy it requires.

Engines

In this connexion, one cannot neglect the applications of atomic energy which are to be expected in the field of propulsion. There was, however, scarcely any mention of this at Geneva—obviously because the Conference was devoted solely to peaceful applications of atomic energy, whereas research on marine or aeronautical engines has military ends in view. That such research eventually also benefits civilian ends is a truth amply supported by the whole history of technology. But is was impossible to speak of research on marine engines, for example, without mentioning the *Nautilus*—and it would have been difficult to speak of a submarine at Geneva.

It is, however, a universal truth that military engines can be advantageously put to civilian uses, once the prototypes, whose high cost is only accepted because of their military uses, have cleared the way for industrial applications. Wartime navies were the first to use liquid fuel, transport planes were derived from bombers, and bulldozers from tanks, while explosives used in factories and quarries have benefited from progress made in their military use. One day, perhaps, the atomic bomb will be used for large-scale civil engineering.

We must expect, therefore, to see first the warship, and only then the merchantman, propelled by atomic energy. The example of the oil-tanker may be quoted as one of the most significant. Any space gained by economizing on the volume of fuel is immediately used for cargo. Now, the profit derived from a tanker is at present governed by the number of round trips which its speed permits. If increased speed is desired, one must increase the power of the engines and, as a result, the cargo space allocated to fuel. The rapid atomic tanker will therefore be a paying proposition. Though its engine will be rather expensive, and will require to be exploited to the full if it is to pay off advantageously, on the other hand the unloading time and perhaps even the loading time can be reduced, since more powerful pumps will be available.

Atomic engines will give large transport planes an independence that should prove most valuable. It is true that the engines will be heavy; but the largest present-day planes carry dozens of tons of fuel, whereas with the new engines a few kilogrammes will be sufficient, and will eliminate expensive halts and the need for fuelling grounds.

All these applications of atomic energy, though they may not become general for twenty years or so, will tend—and this is a basic point—to make available for other purposes the enormous quantities of heavy fuel oils at present consumed for bunkering.

Power Plants

With respect to power plants, we cannot do better than quote here the conclusions of paper A/CONF.8/P/1116 prepared by the Department of Economic and Social Affairs of the United Nations, relating to the place of nuclear energy in the future world power resources. These conclusions seem, indeed, to sum up perfectly the future integration of nuclear power stations with existing sources of energy:

Conventional sources of power, and the demand for energy, are unevenly distributed throughout the world. Lack of correlation in their unequal distribution is only slightly counterbalanced by transport of power, or the substitution of one kind of energy for another. The extent to which these sources are used, in relation to consumption, can therefore only be determined by a thorough study carried out on a national scale.

Moreover, the value of such forecasts diminishes with the length of the period covered by such study.

Costs of electric power produced from traditional sources show a continual upward movement. The cost of nuclear energy, on the contrary, tends to decrease, but prices are not yet stabilized. The point where these two cost curves meet will provide, for each country, . . . an indication of the moment at which it can begin to use this new source of energy. It would seem that only in a very few countries is nuclear energy not destined to play any part in the fifty-year period under consideration. On the contrary, the limits of conventional sources of energy, determined by constantly growing needs as well as by their increasing cost, are going to make the use of this new form of energy imperative for more and more countries. In some of them, this need will be felt very shortly. In the great majority, on the basis of present prices, the integration will be a gradual process. . . .

It is noteworthy, moreover that, in countries leading in the field of atomic energy which have given some idea of their plans, it is this balancing of resources against requirements, either by dint of careful study or by pure instinct, that has determined the way in which the problem has been approached.

Most of the American papers quoted above have mentioned the American five-year plan under which the production of nuclear electricity is approached from five different directions, all aiming, through the construction of successive prototypes, at producing a highly perfected machine which will later enable electricity to be produced at a cost decidedly lower than that of the conventional kilowatt-hour. The explanation is that the United States of America are not in a hurry: they already possess the greatest number of 'mechanical slaves' per head of population; they have numerous rivers which can be harnessed advantageously, more advantageously than atomic energy ever can be; and they have the cheapest coal, together with petroleum and natural gas. As soon as the 'miraculous' machine—the fast breeder reactor, for example—is ready, they will be able to mass produce it; it is well within the capacity of their industry, and the impressive stocks of fissile material built up for military purposes can easily provide the first fuel charges for a whole series of nuclear stations.

The position of Great Britain is very different; here, the need to produce nuclear energy is already being felt. The country can no longer go on increasing its electricity consumption without importing fissile fuel on a large scale. It has no harnessable rivers, no petroleum, no natural gas; and its coal, having to be mined at deeper and deeper levels and hence harder and harder to extract, is becoming increasingly expensive. Accordingly, the United Kingdom is beginning to mass-produce machines of the simplest type, using natural uranium as fuel (A/CONF.8/P/406, by Sir Christopher Hinton). These power stations, producing power immediately at the same price as those working on coal, will make it possible to save millions of tons of coal annually in the years to come.

The British engineering industry is also becoming familiar with nuclear power stations; and, at a later stage, the plutonium produced in the natural-uranium reactors will enable a series of power stations of a more advanced type to be built, such as the fast breeder reactor of which the first prototype is under construction in the North of Scotland (A/CONF.8/P/405, by J. W. Kendall and T. M. Fry).

France occupies an intermediate position between the United States and the United Kingdom, so far as a balance between conventional power supplies and needs is concerned. It is one of the countries in which, on the basis of present prices, integration will be gradual (A/CONF.8/P/327, by P. Ailleret and P. Taranger).

Canada is one of the most favoured countries from the standpoint of conventional sources of energy, chiefly because of its magnificent supplies of water power and the Alberta oilfields. It is accordingly a country in which atomic energy may not play an important part in the next few decades. However, research already carried out shows that atomic energy will enable differences in the price of electricity from one part of the country to another to be reduced, through the placing of a ceiling on prices in the regions least favoured from the standpoint of conventional sources of power (A/CONF. 8/P/11, by J. Davis and W. B. Lewis).

In the least industrialized countries, it is again the relation of supplies to requirements which will determine the use of nuclear energy. Apart from difficulties of construction, operation and maintenance of ultra-modern machines in areas where specialized manpower is scarce, the existence of enormous conventional sources of power as yet unexploited—e.g. the rivers of India and the natural gas of the Middle East—should, in our opinion, have the effect of delaying the utilization of nuclear energy in these countries; nevertheless, even there it must eventually be introduced.

In conclusion, we may say that—from the above examples, as well as from studies presented by other countries as yet less advanced technically in atomic development—it is already clear that 'without judging of the progress which must necessarily be made in this field, nuclear energy will speedily become a preponderant factor in the world power situation' (A/CONF. 8/P/1116, quoted above).